GENERATION OF LONG TIME CREEP DATA ON REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

THIRTEENTH QUARTERLY REPORT

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***TRW* EQUIPMENT LABORATORIES**
CLEVELAND, OHIO

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THIRTEENTH QUARTERLY REPORT

for

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GENERATION OF LONG TIME CREEP DATA OF REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

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FOREWORD

The work described herein is being performed by TRW Inc. under the sponsorship of the National Aeronautics and Space Administration under Contract NAS 3-2545. The purpose of this study is to obtain design creep data on refractory metal alloys for use in advanced space power systems.

The program is administered for TRW Inc. by E. A. Steigerwald, Program Manager. J. C. Sawyer is the Principal Investigator, and R. R. Ebert contributed to the program. The NASA technical director is Paul E. Moorhead

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I INTRODUCTION

Space electric power systems depend upon the use of refractory metals in a variety of component areas. A critical property parameter in the design of these systems is the long-time creep strength at very low pressures and elevated temperatures. Since oxygen contamination of refractory metal alloys can occur under conditions of 1×10^{-6} Torr, vacuums better than 1×10^{-8} Torr must be used to obtain meaningful creep measurements which can be employed in the design of space components. The initial work of this program was to generate 1000 hour creep data on selected refractory alloys which have potential use in advanced power systems. These alloys are in the form of rolled sheet and forged plate with the former being considered as representative of material for cladding and tubing applications and the latter for turbine components. Following the initial evaluation, primary emphasis has been placed on providing long-time (10,000 hour) creep design data for the tantalum-base alloy T-111 and the molybdenum-base TZC and TZM.

This report presents creep data for vapor-deposited tungsten, TZC, TZM, and T-111.

II MATERIALS AND PROCEDURE

The compositions of the various alloys which have been or are being tested are presented in Table 1 while the material form, the range of test temperatures, and heat treatment are given in Table 2. A detailed review of the processing history of the alloys under evaluation was presented in the the Ninth Quarterly Report, NASA-CR-54772.

In the current series of tests, vapor-deposited tungsten is being evaluated as 1/8" diameter bar machined from the wall of vapor-deposited tubing.

TABLE 1

Chemical Composition of Alloys Being Evaluated in Creep Program (Weight %)(1)

Material	W	Re	Cb	Mo	Ta	Hf	C	N_2	Ti	Zr	Ni	ppm O_2	ppm H_2
Tungsten (Vapor Deposited) (General Atomics)	Bal.						.0012					12-14	1-3
Tungsten (Arc-melted)	Bal.						.0058					9	4
Tungsten-25% Rhenium (Arc-melted)	Bal.	24.9					.0050					50	1.4
Sylvania A	Bal.					0.52	.030					20	3
TZM (Heat 7502)				Bal.			.013	.011	.47	.091		20	7
(Heat 7463)				Bal.			.016	.0003	.48	.080		2	1
(Heat KDTZM-1175)				Bal.			.031 (.024)(2)	.0043	.61 (.49)(2)	.12 (.144)(2)		34	9
Cb Modified TZM (Heat 4305-4)			1.62 (1.00)	Bal.			.06 (.015)	(.003)	.50 (.48)	.32 (.095)		(39)	(4) (4)(1)
TZC (Heat M-80)				Bal.			.140	.0018	1.02	.130		41	5
(Heat M-91)				Bal.			.145	.003	1.17	.274		37	10
(Heat 4345)				Bal.			.13		1.24	.15			
AS-30	21.0		Bal.				.090	.010	.03	1.04	.02	60	15
Cb132M	15.6		Bal.	4.73	19.5		.150	.002		2.40		4	2
T-222	9.57				Bal.		.012	.0026				35	11(3)
T-111 (Heat 70616)	8.5				Bal.	2.30	.004	.002				55	6
(Heat D-1670)	7.9				Bal.	2.17-2.44	.001	.002				72	5
(Heat 1102)	Not Received												
(Heat 65079)	Not Received												

(1) - TRW Analysis
(2) - AiResearch Analysis
(3) - Originally ST-222 plate, program plan revised and plate rolled to make T-222 sheet.
(4) - Climax Analysis

TABLE 2

Summary of Material Variables Being Evaluated in the Creep Program

Material	Form	Test Temperature	Test Condition
Tungsten	Arc-Melted 0.030" Sheet	3200°F (1760°C) 2800°F (1538°C)	Recrystallized 1-2 hours, 3200°F (1760°C) Recrystallized 1 hour, 2800°F (1538°C)
Tungsten-25% Rhenium	Arc-Melted 0.030" Sheet	3200°F (1760°C)	Recrystallized 1-2 hours, 3200°F (1760°C)
Sylvania A	Powder Metallurgy 0.030" Sheet	3200°F (1760°C)	Recrystallized 1-2 hours, 3200°F (1760°C)
Tungsten	Vapor-Deposited 1/8" Dia. Bars	3200°F (1760°C) 2800°F (1538°C)	Anneal 1 hour, 3200°F (1760°C) Anneal 1 hour, 2800°F (1538°C)
AS-30	3/4" Plate	2000-2200°F (1093-1204°C)	As-Received (stress-relieved condition)
Cb132M	3/4" Plate	2056-2256°F (1124-1235°C)	Annealed 1 hour, 3092°F (1700°C)
TZM (Heat 7463)	5/8" Diameter Bar	2000°F (1093°C)	Stress relieved 2250°F (1232°C), 1/2 hour
TZM (Climax Heat 7502)	"Pancake" Forging	2000°F (1093°C)	(Cond. 1) As-received (stress-relieved condition)(Cond. 2) Annealed 1 hour, 2850°F (1566°C)
TZM Heat KDTZM-1175 (AiResearch)	"Pancake" Forging	1600-1856°F (871-1013°C)	As-received (stress relieved 2300°F (1260°C), 1 hour)
CB Modified TZM Heat 4305-4	5/8" Diameter Bar	1800-2200°F (982-1204°C)	Stress -relieved 2500°F (1371°C), 1 hour
TZC (Heat M-80) TZC (Heat M-91)	3/4" Plate	1800-2200°F (982-1204°C)	Several test conditions
T-222*	0.030" Sheet	2056-2200°F (1124-1204°C)	Recrystallized 2800°F (1538°C) and 3000°F (1649°C), 1 hour
T-111 (Heat 70616) (Heat D-1670)	0.030" Sheet	1800-2200°F (982-1204°C)	Recrystallized 2600°F (1426°C) and 3000°F (1649°C), 1 hour

* Originally scheduled to be tested as ST-222 plate material, program plan revised to include materials as T-222 grade applicable for tubing.

The TZM alloy was obtained from three different sources. One lot of material, designated as Heat 7502, was purchased from Climax Molybdenum of Michigan in the form of disc forgings approximately 11 inches in diameter, while a second lot of material (Heat KDTZM-1175) consisted of a section of a disc forging obtained from AiResearch. The latter material was processed by Universal Cyclops to produce improved creep resistance (1)* through the development of a fine carbide dispersion. In order to produce this effect it is necessary to work with a carbon level above 0.02%. Climax commercial TZM bar (Heat 7463) has been included in the studies as a means of determining the influence of material form on the creep properties.

To date two different heats of TZC have been tested. These heats (M-80 and M-91) obtained from the same vendor, represent a difference in processing treatment. Heat M-80 involved finishing a 2" x 4" sheet bar by rolling at 2925°F (1585°C) using small reductions per pass (approximately 4%). In contrast M-91 employed a finishing temperature of 2372°F (1300°C) and a relatively large degree of deformation per pass. A third lot of TZC (Heat 4345) was prepared by Climax Molybdenum of Michigan by broad forging 3 inch diameter extruded stock. To date this material has not been tested.

Columbium-modified TZM, a relatively new alloy produced by Climax was tested as a swaged 5/8 inch diameter bar.

Four heats of the T-111 alloy were obtained from two different sources. Two heats were produced by Wah Chang (Heat 70616 and Heat 65079) and two were obtained from Fansteel (Heat D-1670 and Heat 1102). All heats are being evaluated after recrystallization for one hour at 3000°F (1649°C).

The creep-test procedure involved obtaining a vacuum of 5×10^{-10} Torr or better at room temperature, then heating the specimen at a rate so that the pressure never went above 1×10^{-6} Torr. Heat treatment was performed on the materials in situ, prior to load application. After heat treatment the specimens were cooled to 600°F or lower and then reheated to the test temperature which was maintained for two hours to insure equilibrium. During testing the vacuum was less than 1×10^{-8} Torr and decreased with test time.

* Numbers in parentheses refer to references in the Bibliography.

Specimen extension was measured over a two-inch gauge length with an optical extensometer than determined the distance between two scribed reference marks to an accuracy of 50 microinches. The program plan involves testing the plate and forged alloys at temperatures between 1600 and 2250°F (871 and 1235°C) until a 1% total extension is obtained. The tungsten material is being tested at 2800 and 3200°F (1566 and 1760°C) for total extensions between 3 and 5%, while the tantalum base materials are being evaluated in the 1800 to 2600°F (982 to 1427°C) range to an elongation of approximately 2 to 5%. In most cases the applied stress levels have been selected with the goal of obtaining creep data over total test times between 1000 and 20, 000 hours.

III RESULTS AND DISCUSSION

The creep tests in progress, completed or initiated during the thirteenth quarter are graphically presented as percent elongation in the two inch gauge section as a function of the time at the applied stress. Reference marks are placed on the curves to indicate the chamber pressure during the course of the test. The numerical creep data for each test in progress during this quarter are given in detail in Appendix I.

Molybdenum-Base Alloys

Both TZC and TZM molybdenum-base alloys are currently under test. The heat treatments summarized in Table 3 were applied to the materials to provide some indication of whether a recrystallized or stress-relieved structure would provide the greatest degree of creep resistance over the test temperature range being evaluated. In cases where the material was stress relieved prior to test, the stress relief temperature was 200 to 500°F (110 to 280°C) above the test temperature.

TABLE 3

Summary of Heat Treatments Used on Molybdenum-Base Alloys Under Test

Materials	Heat	Treatment
TZC	M-80	Annealed 3092°F (1700°C), 1 Hour
TZC	M-91	Stress Relieved 2300°F (1260°C), 1 Hour
TZC	M-91	Stress Relieved 2500°F (1371°C), 1 Hour
TZC	M-91	Annealed 3092°F (1700°C), 1 Hour
TZM	7502	Stress Relieved 2200°F (1204°C), 1 Hour
TZM	7463	Stress Relieved 2250°F (1232°C), 1/2 Hour
TZM	KDTZM 1175	Stress Relieved 2300°F (1260°C), 1 Hour

The data for the tests of TZC specimens from Heat M-80 are presented in Figure 1. These curves are typified by a region of relatively rapid creep during the first 100-300 hours amounting to an extension of approximately 0.05 to 0.10%. The creep which follows is characterized by a decreasing rate, suggestive of the presence of a strain hardening process.

Four tests of TZC Heat M-91 are being conducted. The creep curves presented in Figure 2 exhibit the general characteristic of a creep rate which constantly decreases with time. A compilation of the Larson-Miller time-temperature parameters to produce 0.5% creep is presented in Table 4 for the various tests on TZC. The results plotted in Figure 3, using a constant of 15, indicate that Heat M-91 in the stress relieved condition provides creep resistance which is superior to that of the same material in the recrystallized condition (compare curves C and D with B). At the lower values of the time-temperature parameter, the 2300°F stress relief produced less creep than the 2500°F treatment (compare curves C and D). A comparison of the results from Heats M-91 and M-80 in the annealed condition indicated that Heat M-80 had superior properties which were comparable to the stress-relieved condition in Heat M-91.

In order to evaluate the influence of processing history on creep resistance, tests under comparable conditions were conducted on TZM material from Heats KDTZM 1175 and 7502 and on Heats 7502 and 7463. The results shown in Figures 4 and 5 indicate that in each series of tests the material with the highest degree of work and room temperature hardness, i.e. the heats KDTZM 1175 and 7463, had the lowest creep rate. Figure 6 compares

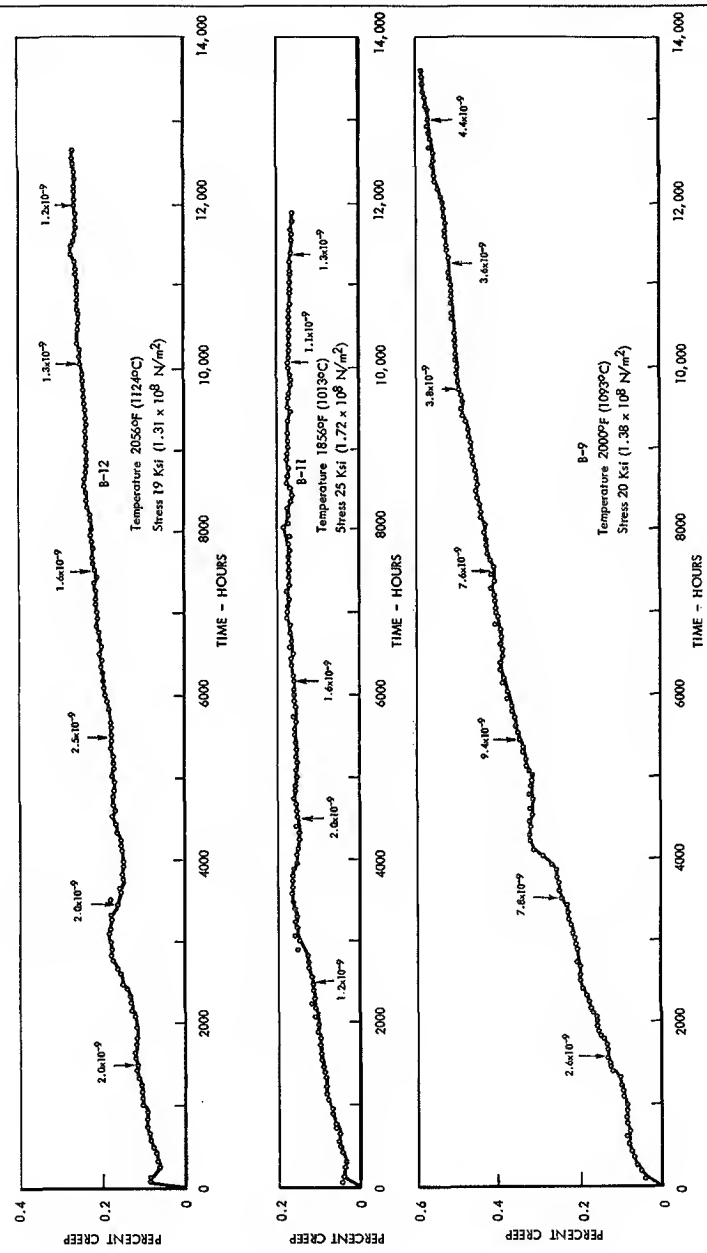


FIGURE 1 CREEP TEST DATA, TZC (HEAT M-80), ANNEALED 3092°F (1700°C) 1 HOUR, TESTED IN VACUUM ENVIRONMENT < 1 X 10⁻⁸ TORR.

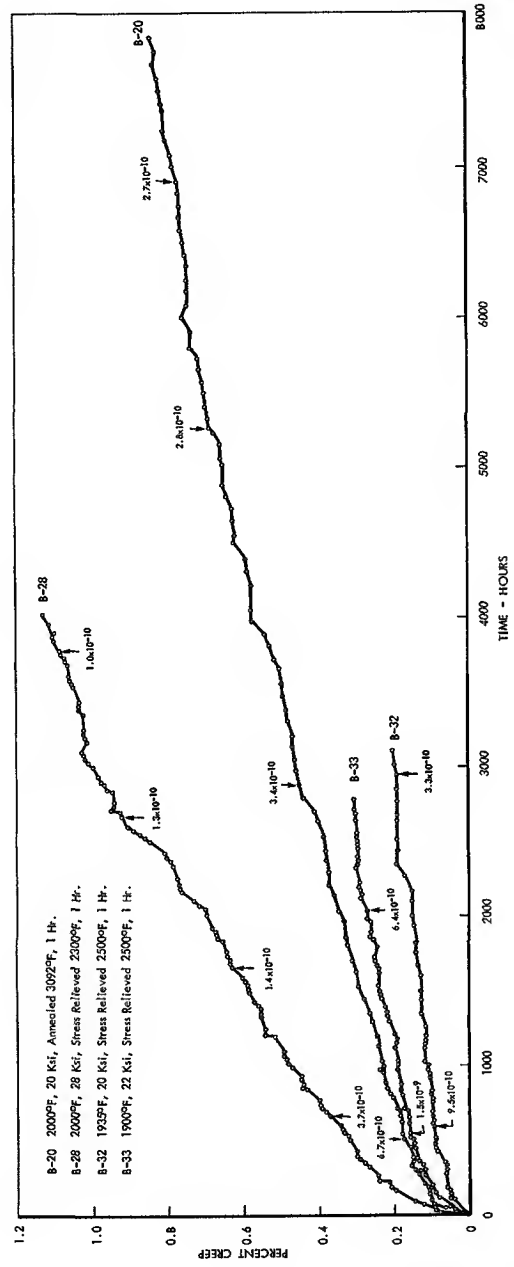


FIGURE 2 CREEP DATA, TZC (HEAT M-91) TESTED IN VACUUM ENVIRONMENT < 1 X 10^{-8} TORR

3029A

TABLE 4

0.5% Creep Test Data for TZC Molybdenum-Base Alloy

Specimen No.	Test Temperature °F	°C	Stress Ksi	$N/m^2 \times 10^8$	Hours for 0.5% Creep	Larson-Miller $T°F(15+\log t)\times 10^{-3}$ for 0.5% Creep
Heat M-80, Annealed 3092°F (1700°C), 1 Hour						
B-8A	2200	1204	18	1.24	1,100	48.0
B-10	2200	1204	17	1.17	2,500	49.0
B-9	2000	1093	20	1.38	10,400	46.8
B-12	2056	1124	19	1.31	46,000*	49.4
B-11	1856	1013	25	1.72	170,000*	46.9
Heat M-91, Annealed 3092°F (1700°C), 1 Hour						
B-31	2200	1204	14	0.965	320	46.6
B-20	2000	1093	20	1.38	3,600	45.6
Heat M-91, Stress Relieved 2300°F (1260°C), 1 Hour						
B-28	2000	1093	28	1.93	1,100	44.4
B-19	1800	982	44	3.03	1,075	40.8
Heat M-91, Stress Relieved 2500°F (1371°C), 1 Hour						
B-30	2200	1204	22	1.52	70	44.9
B-32	1935	1057	20	1.38	20,000*	46.1
B-33	1900	1038	22	1.52	6,000*	44.3

* Extrapolated Data

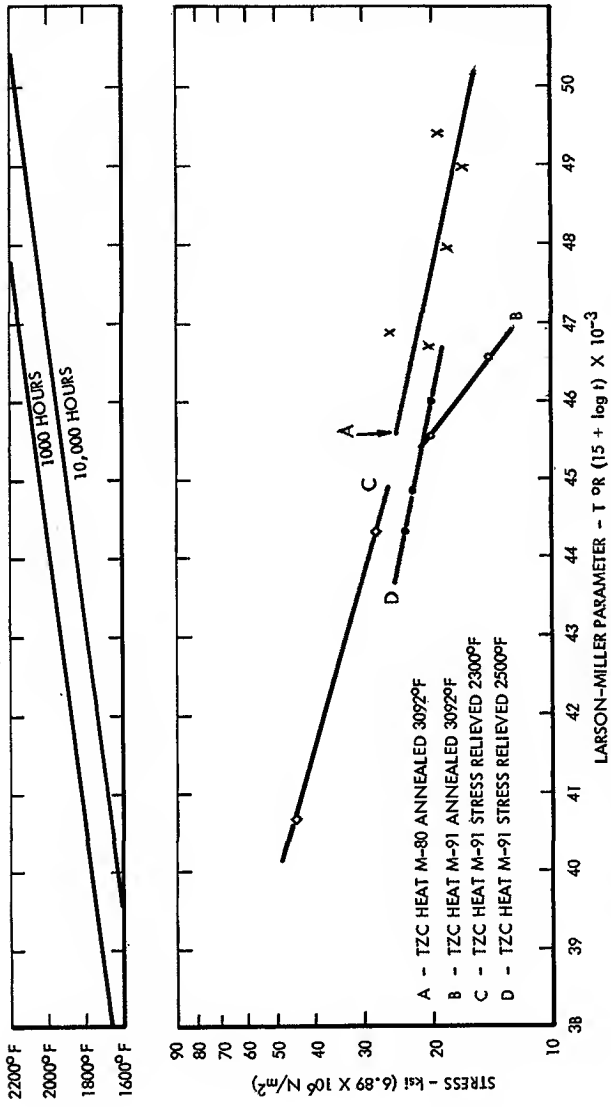


FIGURE 3 LARSON-MILLER PLOT OF DATA FOR 0.5% CREEP IN MOLYBDENUM-BASE TZC ALLOY, TESTED IN VACUUM ENVIRONMENT <1 X 10^{-8} TORR.

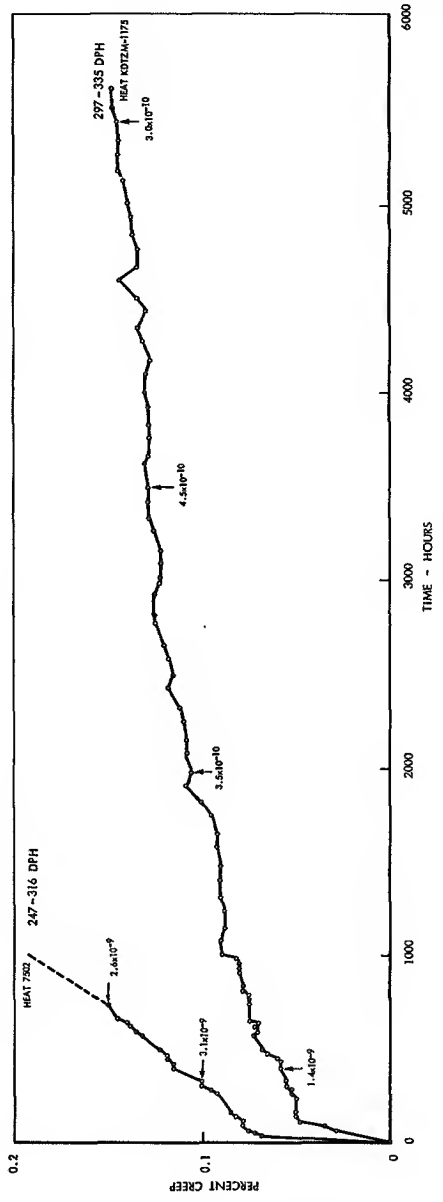


FIGURE 4 CREEP DATA FOR STRESS RELIEVED TZM DISC FORGINGS TESTED AT 1800°F (982°C) AND 44 Ksi (3.03×10^8 N/m^2) IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

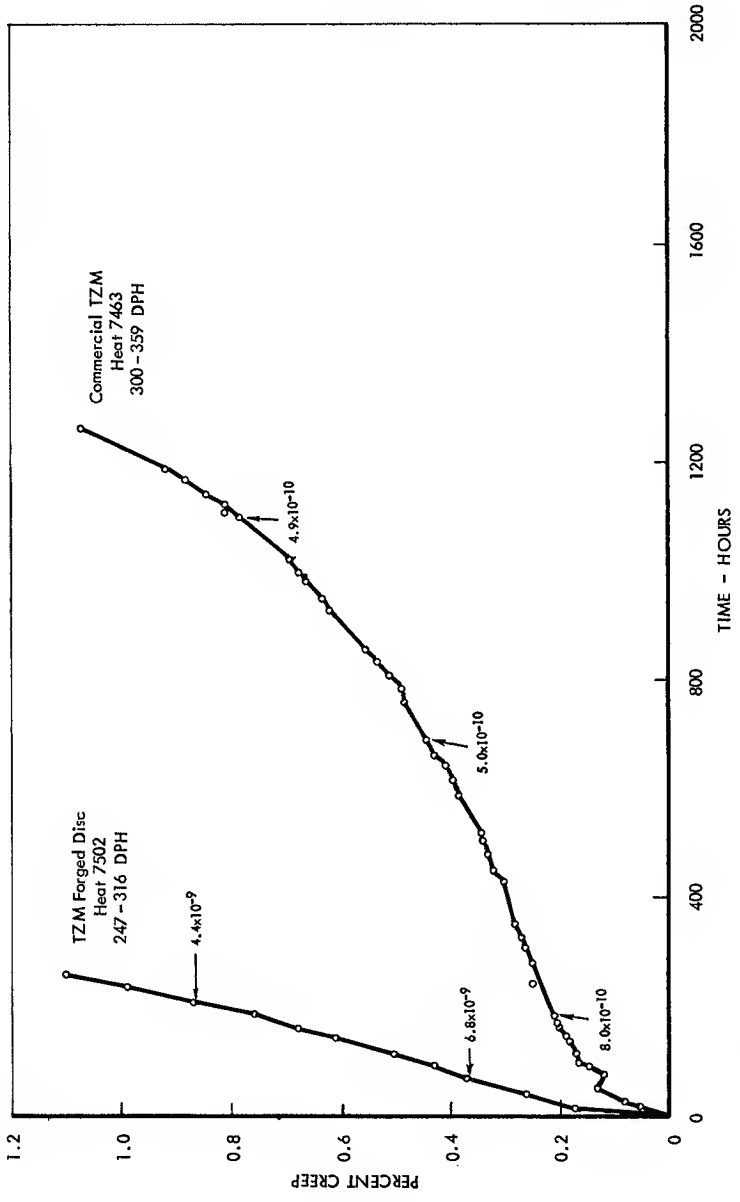
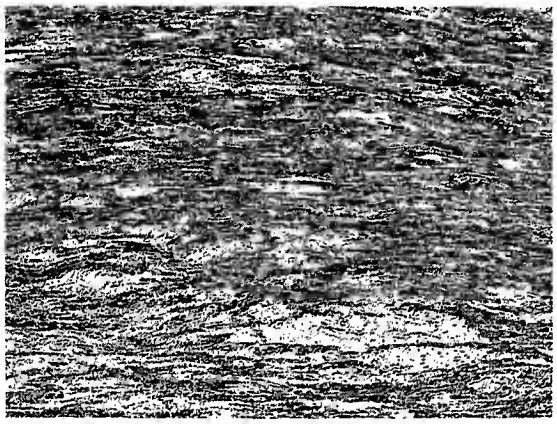
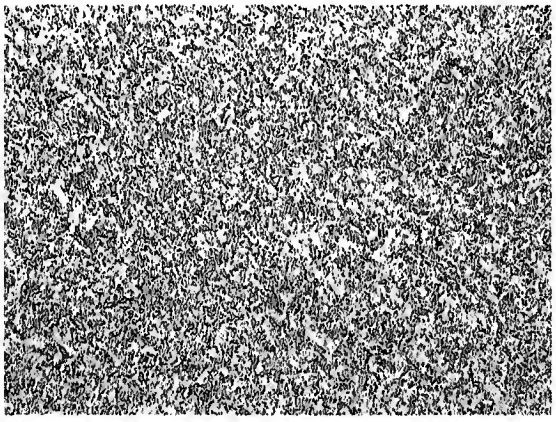


FIGURE 5 CREEP DATA FOR TZM ALLOYS IN STRESS RELIEVED CONDITION. TESTED AT 2000 F (1093°C) AND 41 Ksi (2.82×10^8 N/m^2) IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.



237 DPH TZM DISC HEAT 7502 TEST B-29

TOTAL TEST TIME 664 HRS.



343 DPH TZM BAR HEAT 7463 TEST B-34

TOTAL TEST TIME 1441 HRS.

FIGURE 6 MICROSTRUCTURE 100X OF SURFACE PERPENDICULAR TO SPECIMEN AXIS IN GAUGE SECTION. TEST CONDITIONS 2000°F (1093°C) 41 Ksi (2.82×10^8 N/m^2) IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR. ETCHANT: 75%, HF.

the microstructure of the bar stock (Heat 7463) and the forged disc material (Heat 7502) after testing. The surface shown is in the gauge section perpendicular to the axis of the specimen. The bar material exhibits a considerably higher hardness and has an orientation in which the applied stress is parallel to the fibered grains.

The data shown in Table 5 for various TZM alloys is plotted in terms of the Larson-Miller parameter in Figure 7. In this graph the superiority of Heat KDTZM 1175 is evident. The single points for both commercial TZM bar and Cb-Modified TZM bar indicate that these materials are comparable in creep strength to Heat KDTZM 1175 forged material. In addition, the results indicate that the Cb-modified TZM bar does not have a significantly higher creep strength than the conventional TZM bar. As a direct comparison, the data for TZC Heat M-91 stress relieved at 2300°F is plotted with TZM Heat KDTZM 1175 in Figure 8. The superior creep strength of this particular TZM material at the lower values of the Larson-Miller parameter is apparent. At the higher value of the Larson-Miller parameter which corresponds to a test temperature of 1856°F (1013°C), the creep strength of the KDTZM 1175 decreases from the linear relationship possibly due to recovery effects in the worked structure.

It is worthwhile to examine the TZC data accumulated to date to determine whether it conforms to one of the generalized equations for existing creep theory. This theory states, in part, that the steady state creep rate ($\dot{\varepsilon}$) is related to the temperature and stress in the following manner:

$$\dot{\varepsilon} = A\sigma^n \exp(-Q/RT)$$

where:
- $\dot{\varepsilon}$ = the steady state creep rate
- Q = the activation energy of the creep process
- T = the absolute temperature
- A and n = constants
- σ = stress
- R = the gas constant

Specimen B-30, B-32, and B-33 were tested at various loads and temperatures after stress relieving at 2500°F (1371°C). Using the results from these tests, the steady state creep rate was determined at approximately 1000 hours. While it has been previously stated that the creep rate decreases with time for this alloy, the rate of change is so slow that is was considered essentially constant for this exercise. The data available for the solution of the creep equation are as follows:

TABLE 5

0.5% Creep Test Data for TZM Molybdenum-Base Alloy

Specimen No.	Test Temperature °F	°C	Stress Ksi	$N/m^2 \times 10^8$	Hours for 0.5% Creep	Larson-Miller $T°F(15+\log t)\times 10^{-3}$ for 0.5% Creep
Heat KDTZM 1175, Stress Relieved 2300°F (1260°C), 1 Hour						
B-21	1600	871	65	4.48	9,600*	39.1
B-18	1600	871	55	3.78	60,000*	40.7
B-25	1800	982	44	3.03	50,000*	44.5
B-16	1855	1013	23.4	1.61	62,500*	45.8
Columbium-Modified TZM, Stress Relieved 2500°F (1371°C), 1 Hour						
B-27	2000	1093	41	2.82	1,080	44.4
Heat 7502, Stress Relieved 2200°F (1204°C), 1 Hour						
B-1	2000	1093	12	0.826	605	43.7
B-3	2000	1093	10	0.689	13,000*	47.0
B-29	2000	1093	41	2.82	100	41.9
B-35	1800	982	44	3.03	3,750*	42.0
Commercial Bar, Heat 7463, Stress Relieved 2250°F (1232°C), 1 Hour						
B-34	2000	1093	41	2.82	790	44.0

*Extrapolated Data

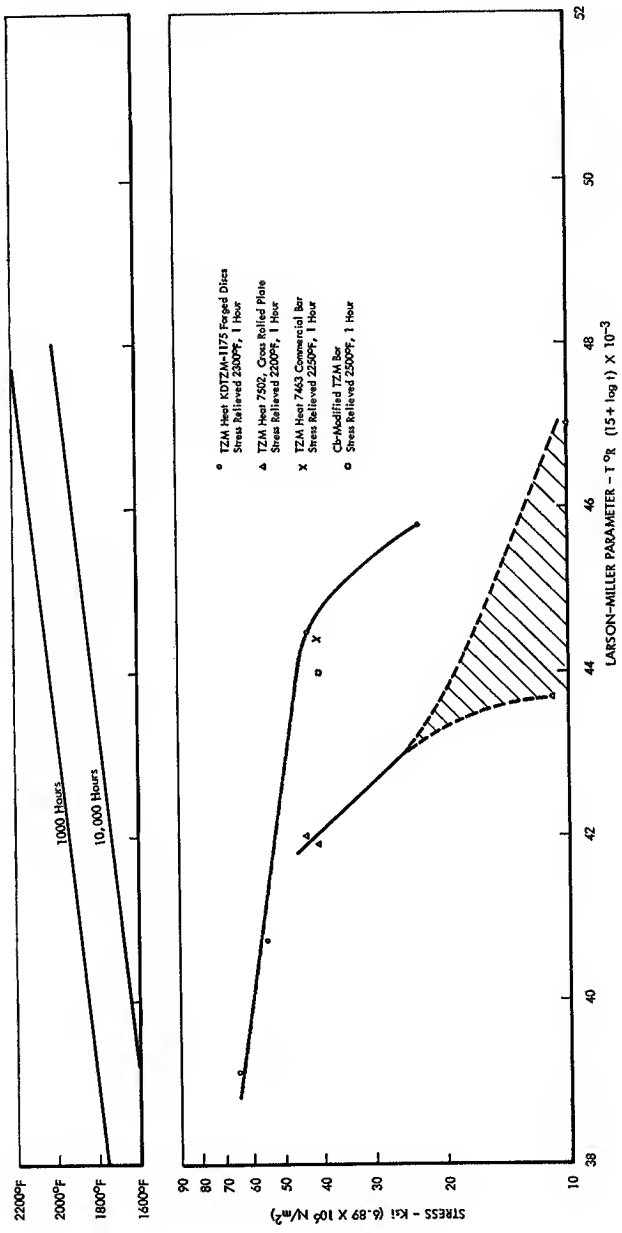


FIGURE 7 LARSON-MILLER PLOT OF DATA FOR 0.5% CREEP IN MOLYBDENUM - BASE TZM ALLOYS, TESTED IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR.

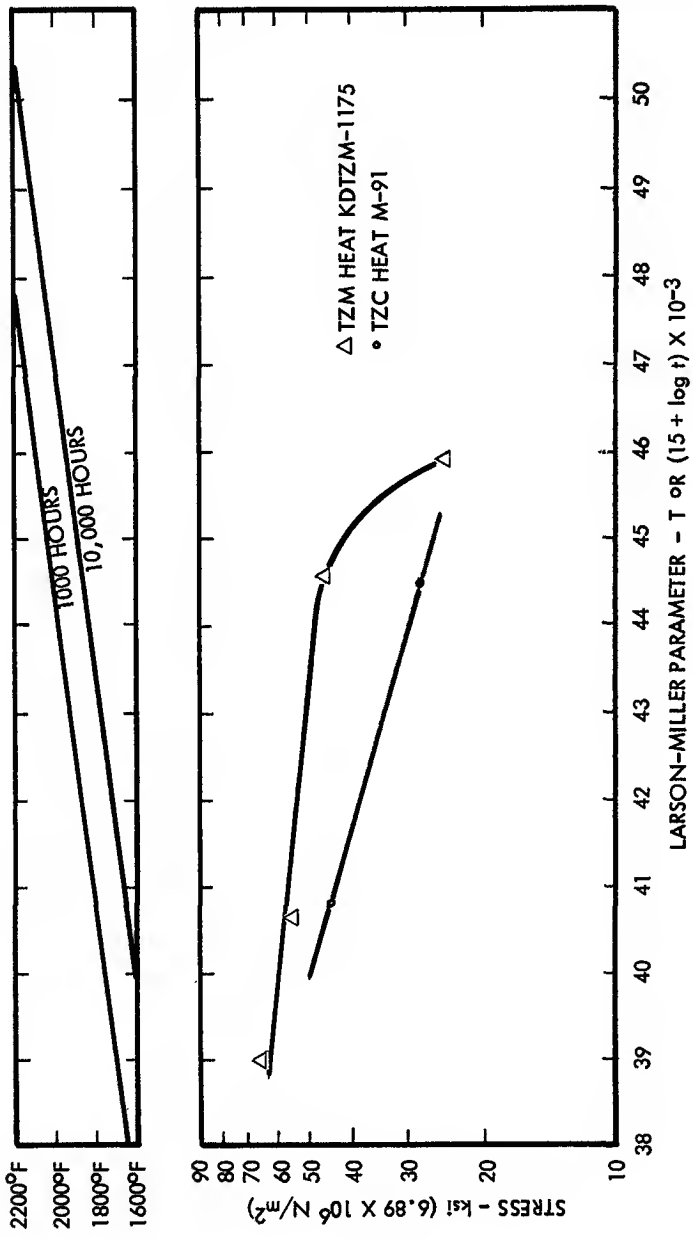


FIGURE 8 LARSON-MILLER PLOT OF DATA FOR 0.5% CREEP IN MOLYBDENUM-BASE ALLOYS, STRESS RELIEVED AT 2300°F (1260°C) AND TESTED IN VACUUM ENVIRONMENT <1 X 10⁻⁸ TORR.

Specimen	Test Temperature °F	°C	°K	Stress ksi	Creep Rate % - Hr.$^{-1}$
B-33	1900	1038	1311	22	7×10^{-5}
B-32	1935	1057	1300	20	3×10^{-5}
B-30	2200	1204	1477	22	4×10^{-3}

The results of the solution show that the apparent activation energy (Q) is 96,000 cal-mole^{-1}-°K^{-1}. This value is in relatively good agreement with 101,000 cal-mole^{-1}-°K^{-1} obtained from the general rule that the activation energy of diffusion is 35 times T_m where T_m is the melting point of the material (2873°K). Since the difference in stress level was too small, no attempt was made to obtain a measure of the stress exponent n.

While this calculation is rather rudimentary, it is indicative of further data which can be obtained with appropriate selection of creep tests.

Tantalum-Base Alloy T-111

Three different lots of tantalum-base T-111 alloys have been tested to date and the results are summarized in Figures 9 and 10. A characteristic of the creep curves is the upware curvature indicative of an accelerating creep rate. In an effort to determine if any microstructural changes were occurring which could account for this effect, a specimen of T-111 was examined which had been annealed for one hour at 3000°F (1649°C) and tested at 2200°F (1204°C) to give 6.55% creep in 3840 hours. The structure of this specimen, shown in Figure 11, suggested the formation of small voids in the grain boundary, or as suggested by Titran and Hall (2) the formation of a second unidentified phase. As a means of further investigation, specimen S-19, annealed 1 hour at 3000°F and tested at 2200°F and 8 Ksi to 3.4% creep was examined with an electron microprobe. The results show the presence of unidentified particles containing a high concentration of hafnium. Similar particles were not found in samples having less extension.

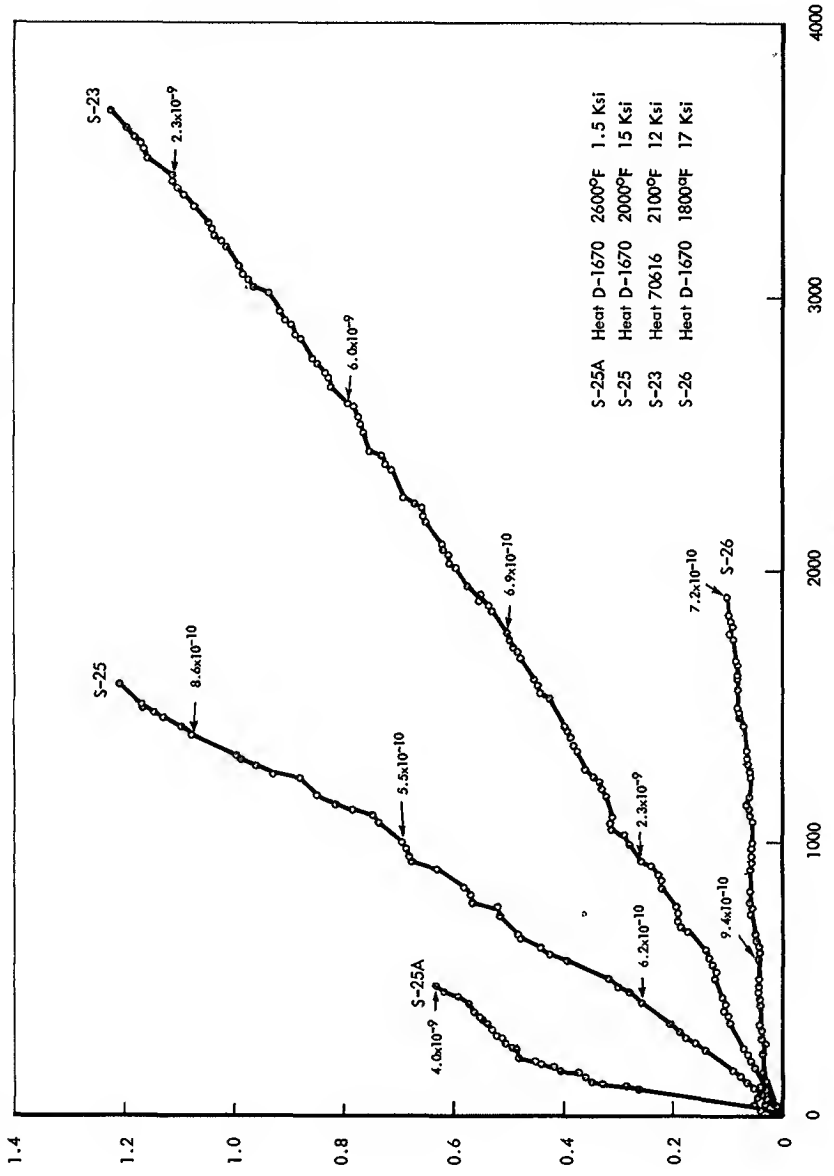


FIGURE 9 CREEP DATA FOR T-111 ALLOY ANNEALED ONE HOUR AT 3000°F (1649°C), TESTED IN VACUUM ENVIRONMENT < 1 X 10^{-8} TORR.

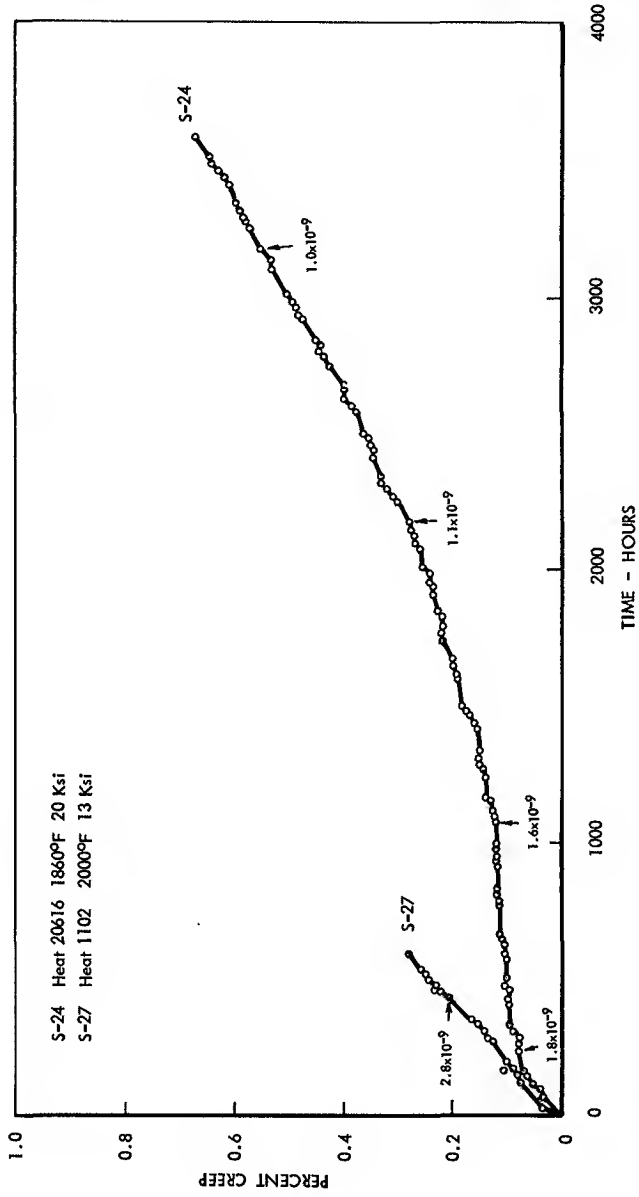
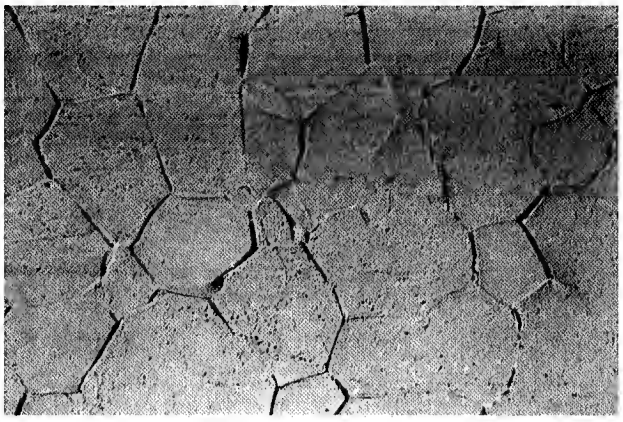


FIGURE 10 CREEP DATA FOR T-111 ALLOY ANNEALED ONE HOUR AT 3000°F (1649°C), TEST IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.



500 X

FIGURE 11 T-111 ANNEALED ONE HOUR 3000°F, TESTED AT 2200°F, AND 12 Ksi for 3840 HOURS. 6.55% CREEP. ETCHANT: 75%, HF, 25% H_2O

A summation of all creep test data for tantalum-base T-111 annealed 1 hour at 3000°F (1649°C) is presented in Table 6 and Figure 12. The difference in creep strength between the various heats tested in this program is not great and the results are represented by a single curve. Data obtained by Westinghouse on T-111 annealed at 3000°F (1649°C) are also shown in the figure and indicate slightly greater creep resistance than the other heats tested.

It is often difficult to predict the time required for 1% creep when a test has progressed to only 0.6% or less. In an effort to improve the prediction capabilities of the data, all of the T-111 test results which exhibited at least 1% creep were normalized with a time base of 10,000 hours. For example, if 1% creep occurred in 5000 hours, the hours associated with each creep reading would be multiplied by two and plotted as a function of the extension. The resulting normalized data points compiled from five tests, shown in Figure 13, indicate that the basic trend of each test curve is similar and no differences can be noted. Although this normalized curve may be peculiar to T-111 it represents a useful method of predicting the 1% creep in the Larson-Miller representations for this material.

Vapor Deposited Tungsten

The creep test results for the vapor-deposited tungsten are presented in Figure 14. No anamolies in the creep behavior are apparent.

IV THERMOCOUPLE DRIFT

Thermocouple drift was discussed in the Ninth Quarterly Report (NAS CR-54773). Because of the availability of additional data, the phenomenon of thermocouple drift was again examined to determine whether any new information could be obtained.

Figures 15, 16, and 17 are examples of the drift of the calibrated tungsten-3% rhenium/tungsten-25% rhenium couples. In all cases the thermocouples were of 20 mil wire. In the hot zone the couple was not insulated; however, a one inch section of beryllia was used to insulate the couple when passing out of the hot zone through the shield pack. In the cold sections of the chamber fused silica protection tubes were used to prevent shorting. In all cases the absolute temperature was maintained by an optical pyrometer once the furnace temperature was set with the calibrated couple. These data show that at approximately 1800-1900°F (982-1038°C) the drift is almost insignificant over a period of 2000 hours. However, after 10,000 hours the decrease in the EMF output may be equivalent to a temperature decrease of as much as 5-10°F (3-6°C). At higher temperatures the amount of drift increased. At 2000°F (1093°C) the thermocouple drift was 18-25°F (10-14°C) in 5000 hours and at 3200°F (1760°C) a drift of 28°F (16°C) was observed after 3500 hours.

TABLE 6

1% Creep Test Data for T-111 Tantalum Base Alloy Annealed 3000°F (1649°C) 1 Hour

Specimen No.	Heat No.	Test Temperature °F	Test Temperature °C	Stress Ksi	Stress $N/m^2 \times 10^8$	Hours for 1% Creep	Larson-Miller $T°R\ (15+\log t) \times 10^{-3}$ for 1% Creep
S-19	70616	2200	1204	8	0.511	2,000	48.6
S-21	70616	2200	1204	12	0.826	1,140	48.0
S-23	70616	2120	1160	12	0.826	3,130	47.7
S-22	70616	2000	1093	20	1.380	670	43.9
S-24	70616	1860	1016	20	1.380	4,800*	43.4
S-25	D-1670	2000	1093	15	1.030	1,350	44.6
S-26	D-1670	1800	982	17	1.170	12,000*	43.0
S-25A	D-1670	2600	1427	1.5	0.103	700*	54.5
S-28	D-1670	2600	1427	0.5	0.034	1,800*	55.9
S-27	1102	2000	1093	13	0.895	1,900*	45.0

* Extrapolated Data

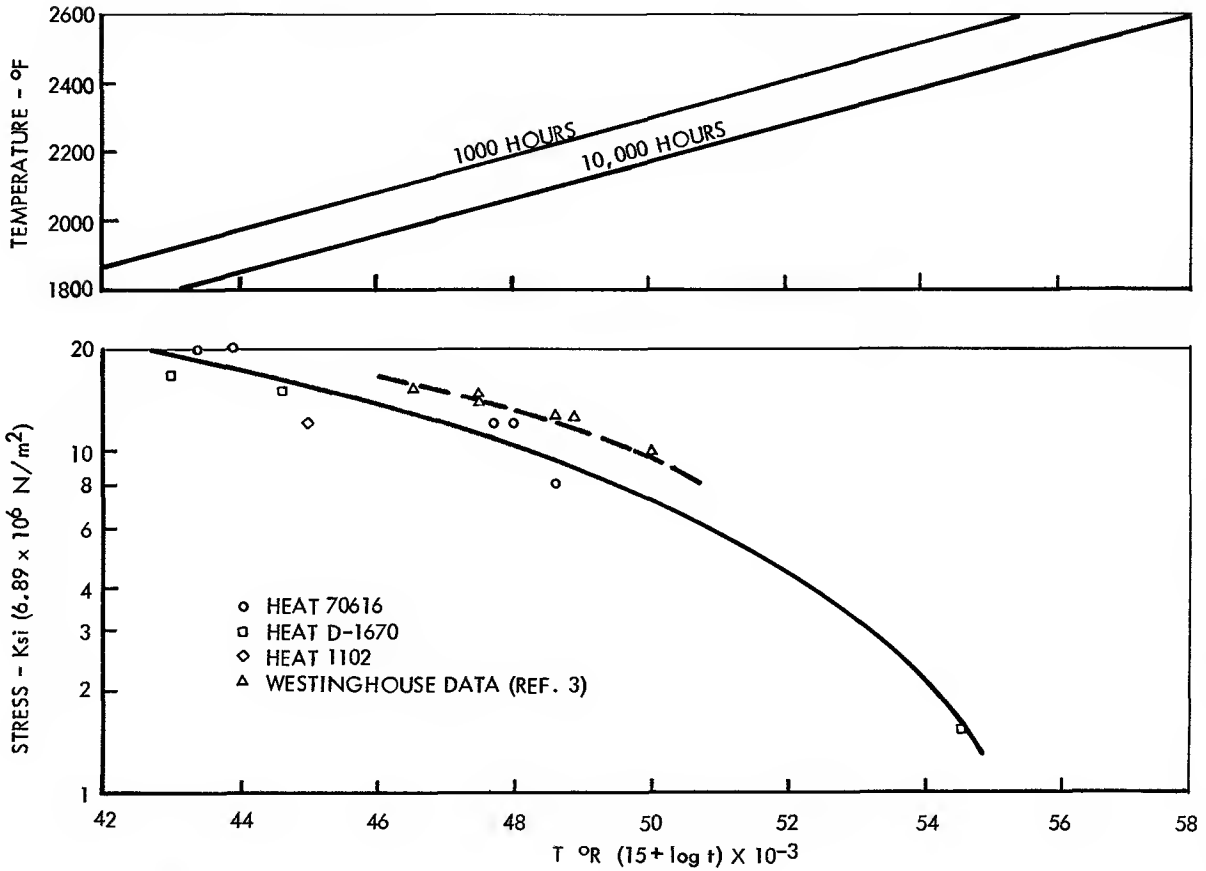


FIGURE 12 LARSON MILLER PLOT OF DATA FOR 1% CREEP IN T-111 ALLOY, ANNEALED 1 HOUR, 3000°F (1649°C), TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

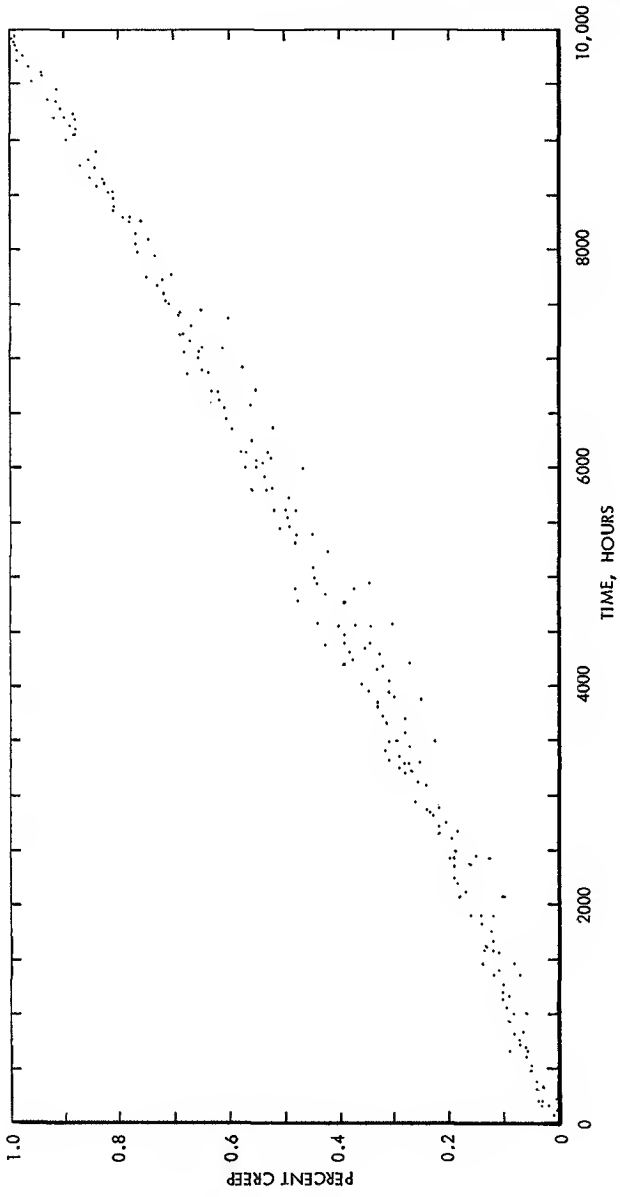


FIGURE 13 NORMALIZED CREEP DATA FOR T-111 ALLOY, ANNEALED 1 HOUR 3000°F (1649°C), TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

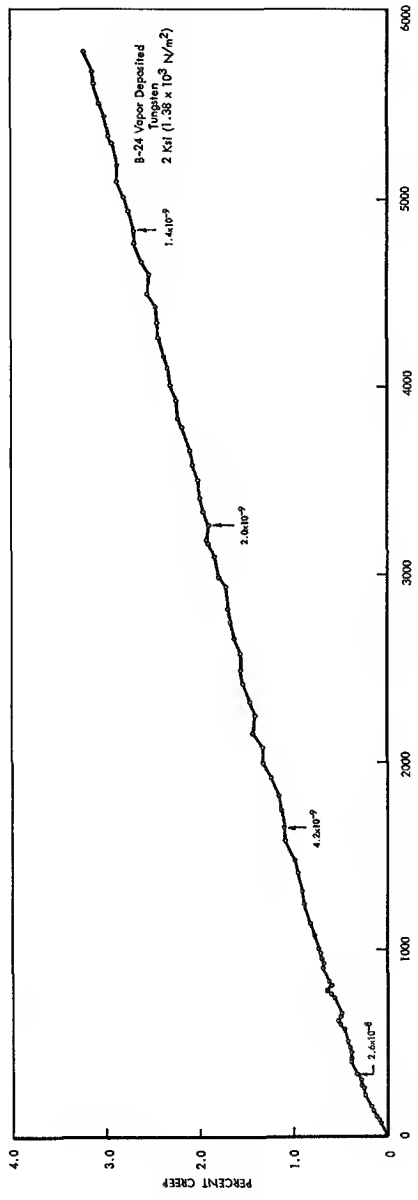


FIGURE 14 CREEP DATA FOR VAPOR-DEPOSITED TUNGSTEN ANNEALED 2800°F, 1 HOUR, AND TESTED AT 2800°F (1538°C) IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR.

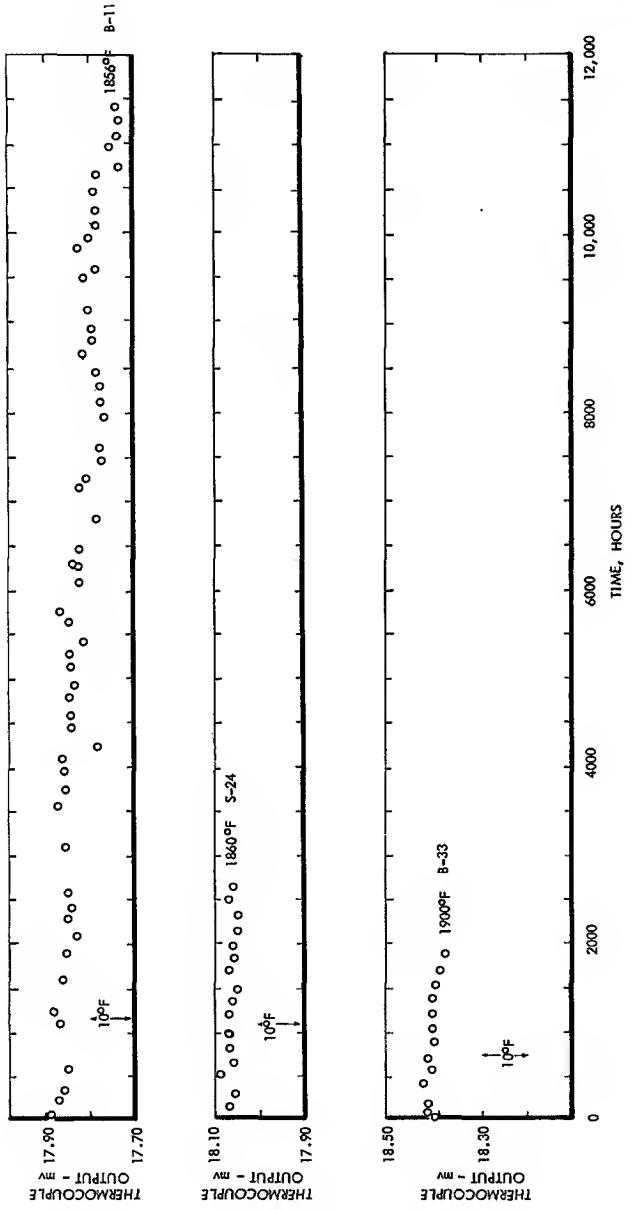


FIGURE 15 VARIATION IN THERMOCOUPLE OUTPUT (W-3% Re VS. W-25% Re) AS A FUNCTION OF TEST TIME IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR, OPTICAL STANDARD.

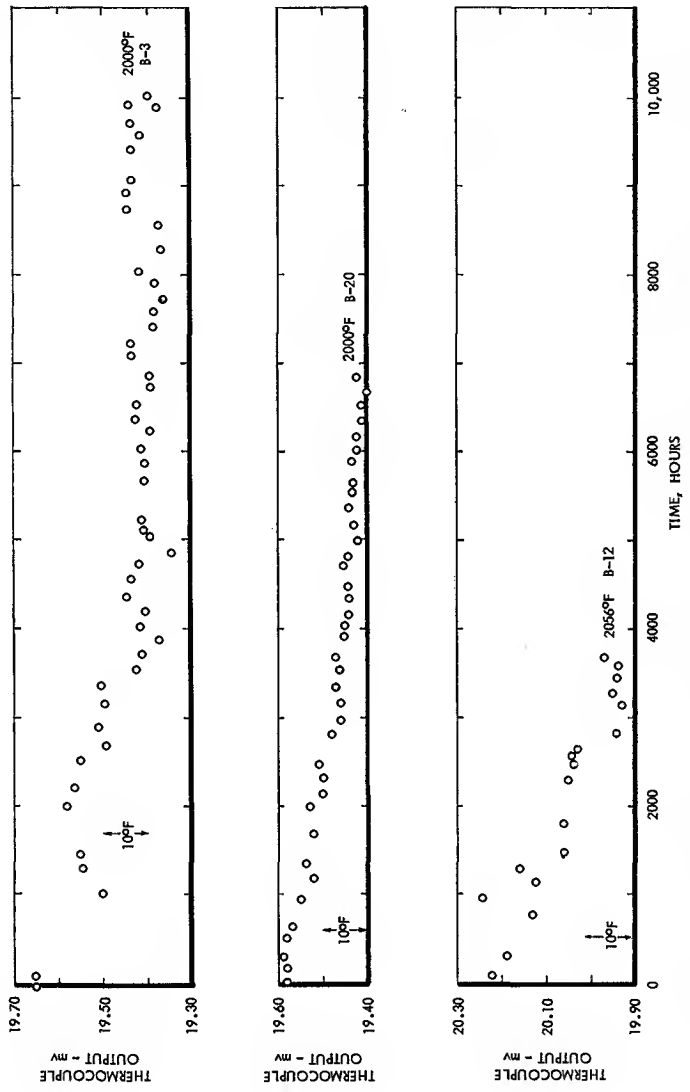


FIGURE 16 VARIATION IN THERMOCOUPLE OUTPUT (W-3% Re VS. W-25% Re) AS A FUNCTION OF TEST TIME IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR, OPTICAL STANDARD.

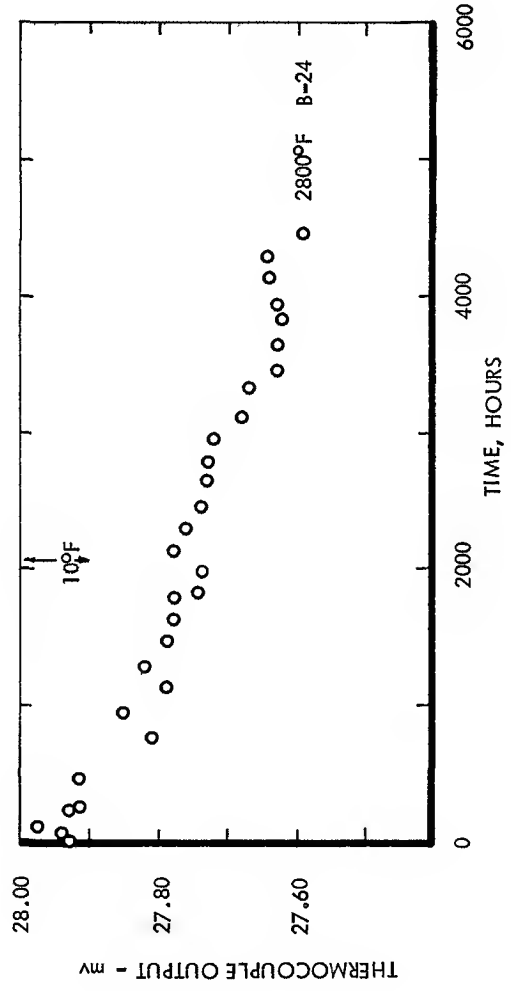


FIGURE 17 VARIATION IN THERMOCOUPLE OUTPUT (W-3% Re Vs. W-25% Re) AS A FUNCTION OF TEST TIME IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR, OPTICAL STANDARD.

Figures 15, 16, and 17 show that a scatter of the EMF readings amounts to about ±0.025 volts which is equivalent to ±2.5°F. The cause of the scatter is not known at this time.

V VACUUM CHAMBER RESIDUAL GAS ANALYSIS

In the Tenth Quarterly Report NAS CR-54895, the residual gas composition was given for vacuum test chambers which had been in operation for several thousand hours. While the analysis showed that the bulk of the residual gas was composed of H_2O, CO-N_2, and CO_2 there was no quantitative correlation in composition between test units. In an effort to determine the variation in gas content during test initiation, Unit No. 3 was analyzed during the anneal and start-up of a T-111 specimen. These results are compiled in Table 7. After pump down at room temperature to 6.0 x 10-8 Torr, 66% of the residual gas (no corrections have been made for ion efficiencies) was found to be water vapor, with the next most prominent gas being CO_2 at 17%. Of particular note is that the helium and argon contents were less than 1% even though these gases are not efficiently pumped.

The unit was then brought to the annealing temperature of 3000°F (1649°C) without bakeout. The rate of heating was such that the pressure never exceeded the top of the 10^{-7} scale and for this reason no specific heating rate was maintained. In this particular test, the unit was held at 1200°F (649°C) for approximately 65 hours to determine the residual gas composition as a function of holding time.

As shown in Table 7, the percent hydrogen of the system initially increased from 2% to 20% as the temperature reached 1200°F (649°C). A first assumption would be that the increase in hydrogen was due to decomposition of water; however, it is entirely possible that some portion of the hydrogen results from outgassing of the new specimen. The percent helium also showed a substantial increase from less than 1% to 6%. The only possible source of the helium is the ion pumps, but it is not understood how the mere act of heating the specimen could cause a sudden evolution of helium from the pumps. The only possible suggestion is that the helium which is involved in the overall gas evolution that occurs during heating cannot be readily repumped. As shown in the table, the percent of hydrocarbons remained relatively constant at 8-12%. In calculating this percentage the column

TABLE 7

Residual Gas Analysis of Unbaked Unit
T-111 Specimen

Time Hrs.	Temperature °F	°C	Pressure Torr	Percent H_2	He	CH_4	CH_4-O	H_2O	$CO-N_2$	A	CO_2
			Mass	2	1	15	16	18	28	40	44
0.0	60	16	6.0×10^{-8}	2	<1	2	6	66	7	<1	17
0.8	400	204	7.0×10^{-7}	19	5	4	8	31	17	10	5
3.1	600	315	6.0×10^{-7}	17	6	3	7	27	19	14	6
5.1	1000	538	6.0×10^{-7}	20	6	3	5	17	29	14	5
6.5	1200	648	6.0×10^{-7}	20	6	2	6	22	23	13	6
71.8	1200	648	6.2×10^{-9}	9	3	0	7	34	30	8	9
73.8	2600	1427	3.7×10^{-9}	19	5	2	6	19	27	11	11
73.9	3000	1649	8.6×10^{-7}	16	5	2	6	16	31	14	10
74.9	3000	1649	4.8×10^{-7}	16	6	3	6	18	27	15	8
75.9	600	315	3.2×10^{-8}	15	8	2	6	24	26	14	4
76.5	2600	1427	2.0×10^{-8}	18	6	2	5	21	28	14	6
77.5	2600	1427	4.0×10^{-8}	17	6	4	6	22	26	12	6
96.5	2600	1427	2.4×10^{-8}	15	4	0	7	28	31	10	6
268.0	2600	1427	5.5×10^{-9}	4	0	0	0	14	65	7	9

designated CH_4-O (mass 16) is presumed to be mostly CH_4. During heating to 1200°F (649°C) a noticeable decrease in the percent water vapor occurred. CO-N_2, at mass 28, is assumed to be mostly CO and its presence is probably due to a reaction of the residual gases with the pump components. During heating to 1200°F (649°C), the CO-N_2 residual gas content increased significantly from 7% to 23%. Argon, being an inert gas like helium, behaved in much the same manner becoming a major gas component during heat-up. At the start, when the system was cold 17% CO_2 was present in the residual gas, but during heat-up the quantity decreased to approximately 5-6%.

As shown in Table 7 the unit was held at 1200°F for 65 hours before continuing with the heat-up to the 3000°F (1649°C) annealing temperature. During this time hydrogen, helium, and argon and CH_4 (mass 15) showed a decrease; however, the CH_4-O at mass did not decrease. During the holding period at 1200°F (649°C) the percent water, CO-N_2 and CO_2 increased.

Application of additional heat caused the gases to assume approximately the same proportions which they had at the start of the 1200°F (649°C) holding period. All of these results suggest that the percent residual gases are more directly related to the heating rate than the temperature.

After annealing the specimen, the power to the furnace was turned off and the unit allowed to cool to 600°F (315°C). As indicated in the table, this had little effect on the percent composition of the residual gas, although the pressure changes by an order of one magnitude. As a result, reheating to the test temperature of 2600°F (1427°C) caused little change in the composition. After 20 hours at 2600°F (1427°C) the changes in the residual gas were in the same direction as when the temperature was held at 1200°F (649°C).

An analysis made after 268 hours at 2600°F (1427°C) shows that the gas composition, during isothermal periods, continues to change beyond 65 hours. Hydrogen decreased to 4%, He and CH_4 decreased to a point where they could no longer be detected, and argon decreased to 7%. As noted before, the percent CO_2 increased slightly from 6 to 9%. CO-N_2 which had showed a moderate increase during the previous holding period at 1200°F (649°C) showed a marked increase during prolonged holding at 2600°F (1427°C). In fact, this specie comprised the bulk of the gas at the 268 hour point. Up to this time, it had been observed that holding for 20 hours at 2600°F (1427°C) or 65 hours at 1200°F (649°C) resulted in an increase in the percent H_2O, but the last analysis at 268 hours shows that a reversal occurs with the percent of water decreasing to a value of 14%.

In summary it may be said that the gas composition during test bears little resemblance to the initial composition. In general, the percent water decreases and the percent CO-N_2 increases to a notable extent.

VI BIBLIOGRAPHY

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2. Robert H. Titran and Robert W. Hall, "Ultrahigh-Vacuum Creep Behavior of Columbium and Tantalum Alloys at 2000°F and 2200°F for Times Greater than 1000 Hours." NASA TN D-3222, January, 1966.

3. R. T. Begley, "Private Communication", Westinghouse Electric Corp., Astronuclear Laboratory, (November, 1966).

APPENDIX I

TABLE I

CREEP TEST DATA, TZC PLATE, HEAT M-80, RECRYSTALLIZED AT 3092°F (1700°C) FOR 1 HOUR, TESTED AT 2000°F (1093°C), 20,000 PSI ($1.38 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00000	.000	1.2×10^{-9}
2	-.00020	-.010	
3	-.00040	-.020	
4	-.00030	-.015	
5	-.00030	-.015	
10	-.00005	-.002	
15	.00005	.002	
20	.00005	.002	
25	.00010	.005	
30	.00010	.005	
60	.00005	.002	
90	-.00005	-.002	
17.2 hours	.00040	.020	2.6×10^{-9}
41.3	.00060	.030	2.2×10^{-9}
65.2	.00080	.040	2.2×10^{-9}
89.2	.00115	.058	2.0×10^{-9}
161.3	.00110	.055	1.3×10^{-9}
185.7	.00130	.065	1.7×10^{-9}
209.1	.00125	.068	1.7×10^{-9}
233.2	.00125	.062	1.4×10^{-9}
257.3	.00130	.065	1.3×10^{-9}
329.2	.00140	.070	2.0×10^{-9}
355.9	.00145	.072	3.2×10^{-9}
377.0	.00145	.072	3.4×10^{-9}
401.1	.00145	.072	2.4×10^{-9}
425.0	.00150	.075	1.5×10^{-9}
497.2	.00170	.085	1.9×10^{-9}
521.4	.00170	.085	3.1×10^{-9}
545.4	.00165	.082	4.8×10^{-9}
569.2	.00170	.085	4.5×10^{-9}
593.1	.00170	.085	4.6×10^{-9}
665.2	.00165	.082	5.0×10^{-9}
713.3	.00160	.080	4.6×10^{-9}
762.8	.00170	.085	--
833.4	.00175	.088	1.5×10^{-8}
881.4	.00185	.092	6.1×10^{-9}
905.2	.00175	.088	5.8×10^{-9}

TABLE I (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1001.1 hours	.00185	.092	3.9×10^{-9}
1049.2	.00185	.092	6.4×10^{-9}
1097.3	.00190	.095	--
1168.4	.00195	.098	4.2×10^{-9}
1216.2	.00200	.100	7.5×10^{-9}
1264.3	.00195	.098	7.0×10^{-9}
1336.7	.00210	.105	7.5×10^{-9}
1389.5	.00250	.125	--
1433.4	.00255	.128	7.2×10^{-9}
1504.2	.00260	.130	1.3×10^{-8}
1552.3	.00270	.135	1.2×10^{-8}
1600.2	.00265	.132	2.6×10^{-9}
1672.4	.00270	.135	5.5×10^{-9}
1720.4	.00275	.138	3.8×10^{-9}
1768.5	.00285	.142	4.6×10^{-9}
1840.1	.00305	.152	4.4×10^{-9}
1894.6	.00310	.155	4.4×10^{-9}
1936.3	.00315	.158	3.8×10^{-9}
1985.6	.00310	.155	3.8×10^{-9}
2032.2	.00325	.162	4.0×10^{-9}
2057.0	.00330	.165	4.0×10^{-9}
2104.1	.00335	.168	3.8×10^{-9}
2176.1	.00345	.172	3.5×10^{-9}
2248.4	.00370	.185	4.2×10^{-9}
2272.2	.00360	.180	7.5×10^{-9}
2344.2	.00375	.188	2.4×10^{-9}
2396.9	.00380	.190	4.6×10^{-9}
2440.2	.00390	.195	4.4×10^{-9}
2512.0	.00400	.200	2.7×10^{-9}
2584.4	.00400	.200	2.9×10^{-9}
2680.2	.00400	.200	7.4×10^{-9}
2752.2	.00405	.202	5.4×10^{-9}
2872.4	.00415	.208	3.8×10^{-9}
2920.8	.00420	.210	6.2×10^{-9}
3016.1	.00425	.212	3.8×10^{-9}
3088.4	.00435	.218	2.6×10^{-9}
3184.6	.00440	.220	4.2×10^{-9}
3256.3	.00450	.225	4.4×10^{-9}

TABLE I (Continued)

Time	Length Change △L (inch) (2" G. L.)	Creep %	Pressure (Torr)
3355.4 hours	.00460	.230	--
3429.1	.00460	.230	--
3530.3	.00490	.245	--
3593.5	.00495	.247	7.8 x 10-9
3689.9	.00500	.250	8.0 x 10-9
3760.5	.00510	.255	8.0 x 10-9
3856.2	.00515	.257	8.2 x 10-9
3928.5	.00525	.262	8.2 x 10-9
4024.1	.00575	.282	8.7 x 10-9
4096.3	.00620	.310	8.2 x 10-9
4192.3	.00640	.320	8.2 x 10-9
4264.1	.00640	.320	8.2 x 10-9
4384.3	.00640	.320	8.4 x 10-9
4432.3	.00640	.320	9.0 x 10-9
4528.3	.00630	.315	8.6 x 10-9
4600.5	.00640	.320	9.4 x 10-9
4696.7	.00625	.312	9.5 x 10-9
4769.2	.00640	.320	8.5 x 10-9
4866.4	.00635	.318	9.2 x 10-9
4936.5	.00630	.315	9.2 x 10-9
5032.5	.00635	.318	9.2 x 10-9
5104.4	.00660	.330	8.4 x 10-9
5200.9	.00660	.330	9.5 x 10-9
5272.3	.00670	.335	8.8 x 10-9
5368.8	.00675	.338	9.4 x 10-9
5440.3	.00685	.342	9.4 x 10-9
5536.2	.00700	.350	1.0 x 10-8
5608.0	.00705	.352	3.4 x 10-9
5705.8	.00715	.358	6.4 x 10-9
5777.0	.00720	.360	4.9 x 10-9
5873.3	.00730	.365	4.9 x 10-9
5945.1	.00745	.372	3.4 x 10-9
6041.2	.00750	.375	2.8 x 10-9
6113.2	.00770	.385	3.4 x 10-9
6209.9	.00770	.385	3.3 x 10-9
6305.5	.00775	.388	3.5 x 10-9
6377.5	.00780	.390	6.3 x 10-9
6449.2	.00775	.388	7.0 x 10-9
6545.7	.00770	.385	8.2 x 10-9
6617.2	.00780	.390	7.4 x 10-9
6713.2	.00780	.390	7.9 x 10-9
6785.3	.00780	.390	7.8 x 10-9
6881.6	.00810	.405	8.0 x 10-9
6953.4	.00790	.395	8.3 x 10-9
7052.7	.00805	.402	8.2 x 10-9
7125.5	.00810	.405	8.1 x 10-9

TABLE I (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
7217.2 hours	.00810	.410	8.2 x 10-9
7386.0	.00815	.408	7.9 x 10-9
7457.2	.00825	.412	7.5 x 10-9
7553.3	.00830	.415	7.6 x 10-9
7625.7	.00835	.418	7.0 x 10-9
7721.9	.00845	.422	7.0 x 10-9
7793.6	.00845	.422	7.3 x 10-9
7889.4	.00850	.425	6.5 x 10-9
7961.2	.00855	.428	7.1 x 10-9
8057.4	.00855	.428	7.4 x 10-9
8129.4	.00860	.430	7.3 x 10-9
8225.3	.00870	.435	5.2 x 10-9
8297.5	.00875	.438	4.3 x 10-9
8393.2	.00880	.440	1.6 x 10-9
8465.6	.00885	.442	4.8 x 10-9
8561.4	.00890	.445	4.8 x 10-9
8633.1	.00895	.448	4.6 x 10-9
8729.1	.00900	.450	5.3 x 10-9
8801.3	.00905	.452	5.2 x 10-9
8969.3	.00915	.458	6.0 x 10-9
9065.3	.00920	.460	7.5 x 10-9
9137.2	.00925	.462	9.6 x 10-9
9233.1	.00930	.465	1.0 x 10-8
9305.3	.00940	.470	1.0 x 10-8
9401.9	.00965	.482	1.0 x 10-8
9476.5	.00970	.485	1.6 x 10-8
9569.4	.00965	.482	2.7 x 10-9
9642.2	.00965	.482	5.4 x 10-9
9737.6	.00960	.480	3.8 x 10-9
9814.3	.00970	.485	5.0 x 10-9
9904.3	.00980	.490	7.6 x 10-9
9976.3	.00980	.490	4.6 x 10-10
10,000.7	.00980	.490	5.2 x 10-10
10,072.1	.00985	.492	8.5 x 10-10
10,144.3	.00985	.492	1.0 x 10-9
10,240.3	.00990	.495	1.5 x 10-9
10,312.1	.00995	.498	1.9 x 10-9
10,408.5	.01005	.502	2.2 x 10-9

TABLE I (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
10,576.5	.01010	.505	3.4×10^{-9}
10,648.2	.01010	.505	3.2×10^{-9}
10,768.7	.01020	.510	2.9×10^{-9}
10,816.2	.01020	.510	2.9×10^{-9}
10,917.0	.01020	.510	3.3×10^{-9}
10,984.1	.01025	.512	3.2×10^{-9}
11,008.1	.01025	.512	4.0×10^{-9}
11,080.2	.01030	.515	3.6×10^{-9}
11,152.5	.01035	.518	3.8×10^{-9}
11,248.2	.01030	.515	3.6×10^{-9}
11,320.3	.01030	.515	3.9×10^{-9}
11,416.5	.01040	.520	4.6×10^{-9}
11,488.2	.01040	.520	4.3×10^{-9}
11,608.2	.01050	.525	4.2×10^{-9}
11,656.9	.01050	.525	4.4×10^{-9}
11,752.4	.01055	.528	4.2×10^{-9}
11,833.2	.01055	.528	7.1×10^{-10}
11,920.2	.01060	.530	1.3×10^{-9}
11,995.5	.01065	.532	1.5×10^{-9}
12,088.7	.01070	.535	2.0×10^{-9}
12,160.4	.01080	.540	2.2×10^{-9}
12,256.6	.01100	.550	2.0×10^{-9}
12,328.8	.01100	.550	2.8×10^{-9}
12,424.3	.01110	.555	3.7×10^{-9}
12,496.1	.01100	.550	3.2×10^{-9}
12,592.3	.01100	.550	3.6×10^{-9}
12,664.1	.01120	.560	4.0×10^{-9}
12,761.1	.01125	.562	4.0×10^{-9}
12,832.3	.01125	.562	4.0×10^{-9}
12,928.1	.01130	.565	4.5×10^{-9}
13,000.3	.01130	.565	4.4×10^{-9}
13,120.9	.01130	.565	4.8×10^{-9}
13,167.9	.01140	.570	5.1×10^{-9}
13,264.4	.01150	.575	4.4×10^{-9}
13,336.0	.01155	.578	4.7×10^{-9}
13,432.8	.01160	.580	4.8×10^{-9}
13,504.4	.01165	.582	5.0×10^{-9}
13,600.2	.01165	.582	1.8×10^{-9}

Test in Progress
Specimen B-9

TABLE II

CREEP TEST DATA, TZC PLATE, RECRYSTALLIZED AT 3092°F (1700°C), FOR 1 HOUR, TESTED AT 1856°F (1013°C). 25,000 psi (1.72 x 10^8 N/m^2)
HEAT M-80

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	-.00005	-.002	
2	.00000	.000	
3	-.00005	-.002	
4	.00005	.002	
5	.00005	.002	
6	.00010	.005	
7	.00005	.002	
8	.00000	.000	
9	.00000	.000	
10	.00005	.002	
15	-.00005	-.002	
20	.00015	.008	
25	.00015	.008	
30	.00025	.012	
60	.00065	.032	
19.3 hours	.00085	.042	1.4×10^{-8}
42.1	.00095	.048	1.3×10^{-8}
68.2	.00095	.048	1.1×10^{-8}
138.4	.00090	.045	5.8×10^{-9}
162.8	.00085	.042	6.6×10^{-9}
186.0	.00085	.042	6.8×10^{-9}
210.3	.00080	.040	5.8×10^{-9}
306.2	.00075	.038	5.2×10^{-9}
330.2	.00090	.045	4.4×10^{-9}
354.2	.00085	.042	3.4×10^{-9}
381.6	.00095	.048	--
402.4	.00095	.048	3.6×10^{-9}
460.7	.00105	.052	2.5×10^{-9}
484.5	.00105	.052	2.8×10^{-9}
508.5	.00125	.062	3.4×10^{-9}
532.4	.00105	.052	3.8×10^{-9}
556.8	.00105	.052	3.2×10^{-9}
628.9	.00105	.052	3.0×10^{-9}
681.7	.00115	.058	--
725.6	.00125	.062	3.1×10^{-9}
796.4	.00130	.065	2.0×10^{-9}
844.8	.00145	.072	2.2×10^{-9}
892.4	.00145	.072	1.6×10^{-9}
964.6	.00140	.070	2.8×10^{-9}

TABLE II (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep %	Pressure (Torr)
1012.6 hours	.00155	.078	2.7×10^{-9}
1060.7	.00170	.085	2.6×10^{-9}
1132.3	.00165	.082	2.4×10^{-9}
1186.9	.00165	.082	2.0×10^{-9}
1228.6	.00170	.085	1.8×10^{-9}
1277.8	.00170	.085	2.2×10^{-9}
1324.4	.00165	.082	2.3×10^{-9}
1349.2	.00175	.088	1.4×10^{-9}
1396.3	.00185	.092	1.8×10^{-9}
1468.3	.00185	.092	2.5×10^{-9}
1516.4	.00180	.090	2.6×10^{-9}
1564.4	.00185	.092	3.1×10^{-9}
1636.4	.00195	.098	2.5×10^{-9}
1689.1	.00205	.102	2.2×10^{-9}
1732.4	.00195	.098	2.8×10^{-9}
1804.3	.00200	.100	2.0×10^{-9}
1876.7	.00215	.108	2.0×10^{-9}
1972.6	.00210	.105	2.3×10^{-9}
2044.4	.00225	.112	9.6×10^{-10}
2164.7	.00225	.112	2.5×10^{-9}
2213.1	.00235	.118	1.4×10^{-9}
2308.3	.00230	.115	1.2×10^{-9}
2380.7	.00235	.118	2.5×10^{-9}
2479.4	.00235	.118	1.2×10^{-9}
2548.4	.00235	.118	2.6×10^{-9}
2647.3	.00245	.122	1.8×10^{-9}
2720.0	.00245	.122	1.1×10^{-9}
2822.6	.00260	.130	9.1×10^{-10}
2886.4	.00305	.152	2.2×10^{-9}
2982.1	.00295	.148	1.6×10^{-9}
3052.8	.00320	.160	1.6×10^{-9}
3148.7	.00315	.158	1.6×10^{-9}
3220.7	.00315	.158	1.6×10^{-9}
3316.4	.00310	.155	1.9×10^{-9}
3388.8	.00315	.158	1.8×10^{-9}
3484.6	.00335	.168	1.6×10^{-9}
3556.4	.00330	.165	1.4×10^{-9}
3676.5	.00335	.168	1.5×10^{-9}
3724.5	.00330	.165	1.9×10^{-9}
3820.7	.00330	.165	1.6×10^{-9}
3892.7	.00320	.160	1.7×10^{-9}
3988.9	.00315	.158	2.8×10^{-9}
4061.4	.00315	.158	1.3×10^{-9}
4158.8	.00300	.150	1.8×10^{-9}
4228.7	.00300	.150	6.0×10^{-10}
4325.1	.00300	.150	1.5×10^{-9}
4396.7	.00315	.158	1.8×10^{-9}
4493.1	.00315	.158	2.0×10^{-9}

1501A

TABLE II (Continued)

Time	Length Change △ L (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
4564.6 hours	.00310	.155	2.0×10^{-9}
4661.2	.00315	.158	1.4×10^{-9}
4732.6	.00320	.160	2.0×10^{-9}
4828.5	.00305	.152	1.7×10^{-9}
4900.3	.00310	.155	1.7×10^{-9}
4998.1	.00305	.152	1.4×10^{-9}
5069.3	.00305	.152	2.4×10^{-9}
5165.5	.00305	.152	1.6×10^{-9}
5237.4	.00310	.155	1.2×10^{-9}
5333.5	.00310	.155	1.1×10^{-9}
5405.5	.00305	.152	1.6×10^{-9}
5502.2	.00305	.152	1.1×10^{-9}
5598.0	.00310	.155	1.4×10^{-9}
5669.8	.00310	.155	1.8×10^{-9}
5741.4	.00320	.160	1.6×10^{-9}
5838.0	.00315	.158	1.6×10^{-9}
5909.4	.00325	.162	1.5×10^{-9}
6005.6	.00315	.158	1.5×10^{-9}
6077.5	.00315	.158	1.6×10^{-9}
6173.9	.00315	.158	1.6×10^{-9}
6245.7	.00320	.160	1.6×10^{-9}
6345.0	.00325	.162	1.0×10^{-9}
6417.7	.00335	.168	1.3×10^{-9}
6509.4	.00335	.168	1.5×10^{-9}
6582.0	.00340	.170	1.0×10^{-9}
6678.2	.00335	.168	1.6×10^{-9}
6749.4	.00340	.170	1.5×10^{-9}
6845.6	.00345	.172	1.6×10^{-9}
6917.9	.00350	.175	2.2×10^{-9}
7014.1	.00355	.178	1.4×10^{-9}
7085.9	.00350	.175	2.1×10^{-9}
7181.9	.00345	.172	2.3×10^{-9}
7253.6	.00355	.178	3.0×10^{-9}
7350.0	.00345	.172	1.4×10^{-9}
7421.6	.00345	.172	1.4×10^{-9}
7517.6	.00345	.172	7.8×10^{-10}
7589.7	.00350	.175	1.8×10^{-9}
7685.4	.00345	.172	1.6×10^{-9}
7757.8	.00340	.170	2.2×10^{-9}
7853.8	.00345	.172	1.8×10^{-9}
7925.4	.00340	.170	1.6×10^{-9}
8021.3	.00340	.170	1.3×10^{-9}
8093.4	.00340	.170	1.6×10^{-9}
8189.3	.00345	.172	1.7×10^{-9}
8261.5	.00345	.172	1.9×10^{-9}
8357.5	.00335	.168	1.1×10^{-9}
8429.5	.00335	.168	1.6×10^{-9}

TABLE II (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
8525.3 hours	.00340	.170	1.7×10^{-9}
8597.7	.00350	.175	1.8×10^{-9}
8694.0	.00355	.178	1.6×10^{-9}
8769.8	.00350	.175	1.7×10^{-9}
8861.7	.00355	.178	1.7×10^{-9}
8934.4	.00355	.178	1.7×10^{-9}
9030.0	.00350	.175	1.7×10^{-9}
9106.9	.00350	.175	1.6×10^{-9}
9197.3	.00350	.175	2.2×10^{-9}
9268.5	.00350	.175	1.5×10^{-9}
9364.7	.00345	.172	1.6×10^{-9}
9436.8	.00335	.168	1.7×10^{-9}
9532.5	.00345	.172	1.7×10^{-9}
9604.3	.00345	.172	1.6×10^{-9}
9700.8	.00345	.172	1.6×10^{-9}
9774.3	.00335	.168	1.7×10^{-9}
9868.8	.00330	.165	1.6×10^{-9}
9940.4	.00340	.170	1.6×10^{-9}
10,060.9	.00345	.172	1.1×10^{-9}
10,108.5	.00340	.170	1.0×10^{-9}
10,207.3	.00335	.168	1.1×10^{-9}
10,276.3	.00335	.168	9.9×10^{-10}
10,300.4	.00340	.170	9.7×10^{-10}
10,372.4	.00340	.170	1.3×10^{-9}
10,444.8	.00335	.168	1.4×10^{-9}
10,540.5	.00345	.172	1.0×10^{-9}
10.612.5	.00340	.170	1.0×10^{-9}
10,708.9	.00335	.168	1.4×10^{-9}
10,780.5	.00335	.168	1.4×10^{-9}
10,900.4	.00340	.170	1.0×10^{-9}
10,949.4	.00340	.170	1.1×10^{-9}
11,044.8	.00340	.170	9.4×10^{-10}
11,125.6	.00340	.170	1.0×10^{-9}
11,212.5	.00340	.170	1.2×10^{-9}
11,287.6	.00335	.168	1.4×10^{-9}
11,381.1	.00330	.165	1.0×10^{-9}
11,453.0	.00300	.150	1.3×10^{-9}
11,549.3	.00330	.165	1.0×10^{-9}
11,621.4	.00335	.168	1.3×10^{-9}
11,716.8	.00340	.170	1.3×10^{-9}
11,788.3	.00330	.165	1.3×10^{-9}
11,844.5	.00330	.165	1.3×10^{-9}
11,956.3	.00310	.155	1.4×10^{-9}

TABLE II (Continued)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
12,054.0	.00320	.160	1.4×10^{-9}
12,124.6	.00325	.162	1.3×10^{-9}
12,220.3	.00325	.162	1.1×10^{-9}
12,292.6	.00335	.168	1.0×10^{-9}
12,413.0	.00345	.172	1.0×10^{-9}
12,460.2	.00340	.170	1.1×10^{-9}
12,556.8	.00335	.168	9.5×10^{-10}
12,628.2	.00340	.170	1.1×10^{-9}
12,725.0	.00345	.172	9.4×10^{-10}
12,796.7	.00345	.172	9.2×10^{-10}
12,892.4	.00350	.175	9.5×10^{-10}

Test in Progress

Specimen B-11

TABLE III

CREEP TEST DATA, TZC PLATE, HEAT M-80, RECRYSTALLIZED AT 3092°F (1700°C), 1 HOUR, TESTED AT 2056°F (1124°C), 19,000 PSI ($1.31 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minutes	.00010	.005	7.0×10^{-8}
2	.00020	.010	
3	.00030	.015	
4	.00050	.025	
5	.00055	.028	
6	.00065	.032	
7	.00085	.042	
8	.00095	.048	
9	.00105	.052	
10	.00120	.060	
12	.00130	.065	
13	.00140	.070	
14	.00150	.075	
15	.00160	.080	6.9×10^{-8}
20	.00165	.082	
25	.00170	.085	
30	.00170	.085	6.9×10^{-8}
40	.00175	.088	
45	.00175	.088	
60	.00180	.090	6.8×10^{-8}
90	.00180	.090	6.7×10^{-8}
15.7 hours	.00180	.090	3.5×10^{-8}
87.1	.00180	.090	1.4×10^{-8}
111.2	.00100	.050	9.8×10^{-9}
133.4	.00140	.070	7.0×10^{-9}
159.0	.00135	.068	3.0×10^{-9}
181.6	.00130	.065	---
239.9	.00135	.068	4.2×10^{-9}
263.7	.00130	.065	5.1×10^{-9}
287.7	.00150	.075	4.5×10^{-9}
309.9	.00140	.070	3.8×10^{-9}
334.3	.00150	.075	3.2×10^{-9}
406.5	.00145	.072	3.5×10^{-9}
459.3	.00155	.078	---
503.2	.00150	.075	2.2×10^{-9}
573.9	.00175	.088	1.2×10^{-9}

TABLE III (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
622.5 hours	.00175	.088	1.1×10^{-9}
669.9	.00180	.090	3.8×10^{-9}
742.3	.00185	.092	2.8×10^{-9}
790.2	.00190	.095	2.8×10^{-9}
838.3	.00185	.092	1.8×10^{-9}
909.9	.00195	.098	3.2×10^{-9}
964.8	.00205	.102	2.6×10^{-9}
1006.2	.00210	.105	2.6×10^{-9}
1055.3	.00215	.108	2.7×10^{-9}
1102.0	.00220	.110	2.9×10^{-9}
1126.8	.00220	.110	1.7×10^{-9}
1173.9	.00220	.110	1.0×10^{-9}
1245.9	.00215	.108	4.2×10^{-10}
1294.0	.00225	.112	2.1×10^{-9}
1342.0	.00235	.118	2.1×10^{-10}
1414.1	.00235	.118	1.4×10^{-9}
1466.7	.00235	.118	2.5×10^{-9}
1509.0	.00225	.112	2.0×10^{-9}
1581.8	.00245	.122	7.5×10^{-10}
1654.2	.00245	.122	1.2×10^{-9}
1750.2	.00240	.120	1.3×10^{-9}
1822.1	.00235	.118	7.0×10^{-10}
1942.2	.00235	.118	8.4×10^{-10}
1990.6	.00240	.120	7.4×10^{-10}
2086.2	.00250	.125	1.6×10^{-9}
2158.2	.00260	.130	1.4×10^{-9}
2254.4	.00265	.132	7.2×10^{-10}
2326.1	.00265	.132	2.0×10^{-9}
2424.7	.00280	.140	1.4×10^{-9}
2497.4	.00305	.152	1.2×10^{-9}
2600.1	.00310	.155	8.0×10^{-10}
2664.7	.00325	.162	2.4×10^{-9}
2759.8	.00345	.172	2.6×10^{-9}
2854.3	.00355	.178	1.5×10^{-9}
2926.3	.00355	.178	1.5×10^{-9}
2998.2	.00355	.178	2.1×10^{-9}
3094.0	.00365	.182	2.1×10^{-9}
3166.4	.00360	.180	2.2×10^{-9}
3262.2	.00355	.178	9.2×10^{-9}

TABLE III (Continued)

Time	Length Change Δ L (inch) (2" G. L.)	Creep %	Pressure (Torr)
3334.1 hours	.00360	.180	2.2×10^{-9}
3454.1	.00340	.170	1.6×10^{-9}
3502.1	.00365	.182	2.0×10^{-9}
3598.2	.00315	.158	1.1×10^{-9}
3670.3	.00315	.158	1.0×10^{-9}
3766.6	.00300	.150	9.0×10^{-10}
3839.0	.00305	.152	2.5×10^{-9}
3936.4	.00300	.150	9.1×10^{-10}
4006.3	.00295	.148	2.0×10^{-9}
4102.6	.00305	.152	2.1×10^{-9}
4174.3	.00310	.155	1.9×10^{-9}
4270.6	.00320	.160	1.0×10^{-9}
4342.2	.00330	.165	2.0×10^{-9}
4438.7	.00330	.165	2.5×10^{-9}
4510.1	.00355	.178	1.4×10^{-9}
4606.2	.00340	.170	2.0×10^{-9}
4677.8	.00345	.172	1.8×10^{-9}
4775.6	.00345	.172	1.8×10^{-9}
4846.8	.00335	.168	1.6×10^{-9}
4943.1	.00335	.168	1.6×10^{-9}
5015.0	.00355	.178	1.7×10^{-9}
5111.1	.00340	.170	1.6×10^{-9}
5183.2	.00345	.172	1.0×10^{-9}
5279.7	.00350	.175	1.6×10^{-9}
5375.6	.00355	.178	1.5×10^{-9}
5447.3	.00355	.178	2.5×10^{-9}
5518.9	.00355	.178	2.5×10^{-9}
5615.6	.00355	.178	1.0×10^{-9}
5687.0	.00360	.180	2.5×10^{-9}
5783.8	.00355	.178	2.4×10^{-9}
5855.1	.00365	.182	2.4×10^{-9}
5951.5	.00375	.188	2.4×10^{-9}
6023.3	.00380	.190	2.5×10^{-9}
6122.5	.00395	.198	9.0×10^{-10}
6195.3	.00390	.195	2.4×10^{-9}
6286.9	.00400	.200	2.5×10^{-9}

TABLE III (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
6359.5 hours	.00405	.202	1.0×10^{-9}
6455.8	.00410	.205	1.7×10^{-9}
6527.0	.00415	.208	2.5×10^{-9}
6623.2	.00410	.205	1.6×10^{-9}
6695.6	.00410	.205	2.3×10^{-9}
6791.8	.00420	.210	1.6×10^{-9}
6864.8	.00420	.210	1.6×10^{-9}
6959.5	.00415	.208	1.4×10^{-9}
7031.2	.00420	.210	2.4×10^{-9}
7127.6	.00435	.218	1.0×10^{-9}
7199.2	.00430	.215	2.2×10^{-9}
7295.2	.00430	.215	7.2×10^{-10}
7367.3	.00430	.215	1.1×10^{-9}
7463.2	.00425	.212	1.0×10^{-9}
7535.5	.00430	.215	1.6×10^{-9}
7631.3	.00440	.220	1.6×10^{-9}
7702.9	.00440	.220	1.6×10^{-9}
7798.9	.00440	.220	1.5×10^{-9}
7870.9	.00440	.220	1.7×10^{-9}
7966.8	.00445	.222	1.6×10^{-9}
8039.1	.00440	.220	1.6×10^{-9}
8135.2	.00450	.225	1.4×10^{-9}
8207.0	.00455	.228	1.4×10^{-9}
8302.8	.00465	.232	1.4×10^{-9}
8375.2	.00470	.235	1.4×10^{-9}
8471.6	.00475	.238	1.3×10^{-9}
8546.4	.00480	.240	1.4×10^{-9}
8639.3	.00480	.240	1.4×10^{-9}
8712.3	.00480	.240	1.3×10^{-9}
8807.6	.00470	.235	1.3×10^{-9}
8885.0	.00470	.235	1.4×10^{-9}
8975.7	.00470	.235	1.3×10^{-9}
9046.1	.00475	.238	1.4×10^{-9}
9142.2	.00475	.238	1.3×10^{-9}
9214.3	.00475	.238	1.4×10^{-9}
9310.0	.00475	.238	1.3×10^{-9}
9381.9	.00480	.240	1.4×10^{-9}
9478.8	.00480	.240	1.4×10^{-9}
9551.8	.00485	.242	1.3×10^{-9}
9646.4	.00485	.242	1.3×10^{-9}
9718.0	.00485	.242	1.4×10^{-9}
9838.4	.00490	.245	1.4×10^{-9}
9886.2	.00495	.248	1.4×10^{-9}
9985.1	.00500	.250	1.4×10^{-9}

TABLE III (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
10,053.9	.00500	.250	1.3 x 10-9
10,077.9	.00500	.250	1.3 x 10-9
10,150.1	.00500	.250	1.4 x 10-9
10,222.5	.00505	.252	1.3 x 10-9
10,318.1	.00510	.255	1.3 x 10-9
10,390.8	.00510	.255	1.3 x 10-9
10,486.6	.00505	.252	1.3 x 10-9
10,558.1	.00510	.255	1.3 x 10-9
10,678.1	.00505	.252	1.2 x 10-9
10,727.0	.00510	.255	1.2 x 10-9
10,822.5	.00515	.258	1.2 x 10-9
10,903.1	.00515	.258	1.2 x 10-9
10,990.1	.00515	.258	1.2 x 10-9
11,064.4	.00515	.258	1.2 x 10-9
11,158.7	.00525	.262	1.2 x 10-9
11,230.8	.00520	.260	1.2 x 10-9
11,327.3	.00525	.262	1.2 x 10-9
11,400.2	.00540	.270	1.2 x 10-9
11,494.4	.00545	.272	1.2 x 10-9
11,565.8	.00535	.266	1.2 x 10-9
11,662.1	.00520	.260	1.2 x 10-9
11,733.8	.00525	.262	1.2 x 10-9
11,832.2	.00525	.262	1.2 x 10-9
11,902.3	.00525	.262	1.2 x 10-9
11,998.9	.00530	.265	1.2 x 10-9
12,070.2	.00530	.265	1.2 x 10-9
12,190.6	.00530	.265	1.3 x 10-9
12,237.8	.00530	.265	1.3 x 10-9
12,334.5	.00530	.265	1.4 x 10-9
12,405.9	.00530	.265	1.2 x 10-9
12,502.6	.00530	.265	1.2 x 10-9
12,574.2	.00535	.268	1.2 x 10-9
12,670.0	.00535	.268	1.2 x 10-9

Test in Progress
Specimen B-12

TABLE IV

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED AT 3000°F (1649°C) FOR 1 HOUR, TESTED AT 2100°F (1149°C), 12,000 PSI (8.28×10^7 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute(s)	.00000	.000	3.0×10^{-9}
2	.00005	.002	3.0×10^{-9}
3	.00010	.005	3.0×10^{-9}
4	.00015	.008	3.0×10^{-9}
5	.00015	.008	3.0×10^{-9}
6	.00010	.005	3.0×10^{-9}
7	.00010	.005	3.0×10^{-9}
8	.00005	.002	3.0×10^{-9}
9	.00010	.005	3.0×10^{-9}
10	.00005	.002	3.0×10^{-9}
15	.00000	.000	3.0×10^{-9}
30	.00005	-.002	3.0×10^{-9}
45	.00010	.005	3.0×10^{-9}
60	.00010	.005	3.0×10^{-9}
19.6 Hours	.00025	.012	3.1×10^{-9}
50.1	.00060	.030	2.4×10^{-9}
67.5	.00070	.035	2.3×10^{-9}
91.5	.00080	.040	2.4×10^{-9}
164.0	.00100	.050	2.1×10^{-9}
187.5	.00115	.058	2.1×10^{-9}
211.3	.00125	.062	2.2×10^{-9}
238.7	.00140	.070	2.2×10^{-9}
331.5	.00190	.095	1.7×10^{-9}
355.6	.00195	.098	1.8×10^{-9}
379.3	.00205	.102	2.3×10^{-9}
404.3	.00205	.102	2.3×10^{-9}
427.4	.00215	.108	1.9×10^{-9}
499.8	.00245	.122	2.2×10^{-9}
523.3	.00240	.120	2.2×10^{-9}
547.5	.00250	.125	2.2×10^{-9}
576.4	.00270	.135	2.2×10^{-9}
595.3	.00275	.138	2.4×10^{-9}
667.2	.00340	.170	2.5×10^{-9}
690.6	.00370	.185	2.4×10^{-9}

TABLE IV (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
714.4	.00380	.190	2.3×10^{-9}
738.5	.00385	.192	2.4×10^{-9}
762.9	.00385	.192	2.4×10^{-9}
834.3	.00440	.220	2.4×10^{-9}
858.4	.00445	.222	2.3×10^{-9}
882.5	.00455	.228	2.3×10^{-9}
906.7	.00480	.240	2.3×10^{-9}
930.3	.00515	.258	2.3×10^{-9}
1002.4	.00560	.280	2.2×10^{-9}
1026.2	.00575	.288	2.2×10^{-9}
1050.4	.00620	.310	2.2×10^{-9}
1074.2	.00630	.315	2.2×10^{-9}
1098.6	.00620	.310	2.2×10^{-9}
1170.7	.00640	.320	2.2×10^{-9}
1194.3	.00655	.328	2.2×10^{-9}
1218.3	.00665	.332	2.2×10^{-9}
1242.5	.00690	.345	2.2×10^{-9}
1266.3	.00715	.358	2.3×10^{-9}
1338.7	.00750	.375	2.3×10^{-9}
1362.5	.00760	.380	2.3×10^{-9}
1386.3	.00775	.388	2.2×10^{-9}
1410.4	.00785	.392	2.2×10^{-9}
1434.3	.00795	.398	2.2×10^{-9}
1530.8	.00850	.425	6.7×10^{-10}
1554.5	.00880	.440	6.8×10^{-10}
1578.4	.00890	.445	6.8×10^{-10}
1602.4	.00905	.452	2.2×10^{-9}
1677.5	.00955	.478	2.2×10^{-9}
1698.3	.00965	.482	6.7×10^{-9}
1722.3	.00980	.490	2.1×10^{-9}
1746.2	.00990	.495	6.6×10^{-10}
1770.2	.00995	.498	6.9×10^{-10}
1842.3	.01055	.528	2.0×10^{-9}
1866.3	.01070	.535	2.0×10^{-9}
1890.4	.01100	.550	6.3×10^{-10}
1914.6	.01095	.548	2.2×10^{-9}
1938.3	.01145	.572	6.4×10^{-10}
2010.4	.01190	.595	2.1×10^{-9}
2034.3	.01210	.605	6.3×10^{-10}
2058.4	.01220	.610	6.4×10^{-10}
2082.4	.01235	.618	6.3×10^{-10}

TABLE IV (Continued)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
2106.6 Hours	.01240	.620	2.1×10^{-9}
2178.7	.01300	.650	6.1×10^{-10}
2202.6	.01310	.655	6.4×10^{-10}
2226.1	.01310	.655	2.1×10^{-9}
2250.4	.01340	.670	6.4×10^{-10}
2274.3	.01375	.688	6.3×10^{-10}
2370.3	.01430	.715	6.1×10^{-10}
2394.4	.01445	.722	6.4×10^{-10}
2419.1	.01465	.732	2.0×10^{-9}
2442.3	.01505	.752	2.0×10^{-9}
2514.7	.01530	.765	2.2×10^{-9}
2538.5	.01540	.770	2.2×10^{-9}
2564.4	.01545	.772	1.8×10^{-9}
2595.6	.01560	.780	1.7×10^{-9}
2610.4	.01575	.788	6.0×10^{-9}
2682.4	.01640	.820	6.0×10^{-10}
2706.4	.01650	.825	6.0×10^{-10}
2730.4	.01660	.830	2.0×10^{-9}
2757.6	.01690	.845	6.2×10^{-9}
2779.2	.01710	.855	6.1×10^{-10}
2850.9	.01755	.878	2.0×10^{-9}
2874.8	.01775	.888	1.6×10^{-9}
2898.6	.01795	.898	1.8×10^{-9}
2922.7	.01810	.905	2.0×10^{-9}
2946.7	.01830	.915	1.5×10^{-9}
3018.8	.01875	.938	6.0×10^{-10}
3042.6	.01930	.965	5.8×10^{-10}
3066.6	.01950	.975	1.9×10^{-9}
3091.0	.01970	.985	1.9×10^{-9}
3115.2	.01980	.990	5.9×10^{-10}
3186.5	.02030	1.015	1.9×10^{-9}
3210.7	.02050	1.025	1.8×10^{-9}
3234.2	.02070	1.035	5.9×10^{-10}
3258.2	.02080	1.040	1.8×10^{-9}
3282.3	.02090	1.045	5.9×10^{-10}
3354.5	.02150	1.075	4.8×10^{-9}
3378.3	.02180	1.090	3.2×10^{-9}
3402.1	.02205	1.102	2.7×10^{-9}
3426.2	.02220	1.110	2.4×10^{-9}
3450.0	.02220	1.110	2.3×10^{-9}
3523.6	.02315	1.158	2.1×10^{-9}
3546.2	.02330	1.165	2.0×10^{-9}
3594.5	.02355	1.178	2.1×10^{-9}
3690.3	.02440	1.220	2.0×10^{-9}
3698.2	.02450	1.225	2.0×10^{-9}

Test terminated - 1% Creep
Specimen S-23

TABLE V

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 3092°F (1700°C) FOR 1 HOUR, TESTED AT 2000°F (1093°C), 20,000 PSI ($1.38 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minutes	.00000	.000	8.2×10^{-9}
2	.00005	.002	8.2×10^{-9}
3	.00010	.005	8.2×10^{-9}
4	.00010	.005	8.2×10^{-9}
5	.00015	.008	8.2×10^{-9}
6	.00020	.010	8.2×10^{-9}
7	.00020	.010	8.2×10^{-9}
8	.00020	.010	8.2×10^{-9}
9	.00015	.008	8.2×10^{-9}
10	.00020	.010	8.2×10^{-9}
15	.00025	.012	8.2×10^{-9}
20	.00020	.010	8.2×10^{-9}
25	.00025	.012	8.2×10^{-9}
30	.00025	.012	8.2×10^{-9}
60	.00020	.010	8.2×10^{-9}
1.7 Hours	.00030	.015	8.2×10^{-9}
19.0	.00075	.038	8.4×10^{-9}
43.9	.00100	.050	7.2×10^{-9}
115.2	.00155	.078	4.0×10^{-9}
139.2	.00185	.092	3.2×10^{-9}
163.6	.00210	.105	2.6×10^{-9}
187.1	.00220	.110	2.4×10^{-9}
211.4	.00240	.120	2.1×10^{-9}
283.2	.00270	.135	1.4×10^{-9}
307.3	.00290	.145	1.2×10^{-9}
331.2	.00300	.150	1.1×10^{-9}
355.2	.00295	.148	9.7×10^{-10}
379.3	.00295	.148	9.6×10^{-10}
451.9	.00310	.155	7.9×10^{-10}
499.6	.00350	.175	6.7×10^{-10}
547.7	.00355	.178	6.1×10^{-10}
619.5	.00360	.180	9.2×10^{-10}
643.4	.00365	.182	6.3×10^{-10}
667.4	.00365	.182	8.1×10^{-10}
691.1	.00365	.182	8.2×10^{-10}
715.5	.00375	.188	7.8×10^{-10}

TABLE V (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
787.7 Hours	.00410	.205	7.4×10^{-10}
811.6	.00420	.210	7.1×10^{-10}
835.3	.00435	.218	7.2×10^{-10}
859.2	.00440	.220	7.0×10^{-10}
883.2	.00445	.222	7.0×10^{-10}
956.3	.00460	.230	6.6×10^{-10}
980.0	.00470	.235	6.4×10^{-10}
1003.4	.00455	.228	6.4×10^{-10}
1027.2	.00465	.232	6.2×10^{-10}
1123.7	.00485	.242	6.0×10^{-10}
1195.5	.00490	.245	5.7×10^{-10}
1294.7	.00515	.258	6.0×10^{-10}
1367.4	.00525	.262	5.8×10^{-10}
1459.1	.00560	.280	5.6×10^{-10}
1531.7	.00585	.292	5.4×10^{-10}
1627.9	.00600	.300	5.4×10^{-10}
1699.2	.00620	.310	5.4×10^{-10}
1795.3	.00640	.320	5.4×10^{-10}
1867.8	.00655	.328	5.1×10^{-10}
1963.9	.00665	.332	5.1×10^{-10}
2035.6	.00695	.348	4.7×10^{-10}
2131.6	.00720	.360	4.8×10^{-10}
2203.3	.00740	.370	4.9×10^{-10}
2299.8	.00745	.372	4.9×10^{-10}
2371.4	.00755	.378	4.8×10^{-10}
2467.3	.00760	.380	3.6×10^{-10}
2539.5	.00770	.385	2.6×10^{-10}
2635.2	.00800	.400	3.8×10^{-10}
2707.6	.00820	.410	3.4×10^{-10}
2803.4	.00880	.440	3.4×10^{-10}
2875.1	.00900	.450	3.4×10^{-10}
2971.0	.00910	.455	3.1×10^{-10}
3043.1	.00920	.460	3.6×10^{-10}
3139.0	.00935	.468	3.3×10^{-10}
3211.3	.00930	.465	3.4×10^{-10}
3307.3	.00960	.480	3.3×10^{-10}
3379.2	.00965	.482	3.2×10^{-10}

TABLE V (Continued)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
3475.0 Hours	.00980	.490	3.4×10^{-10}
3547.4	.00990	.495	3.2×10^{-10}
3643.8	.00995	.498	3.2×10^{-10}
3718.6	.01020	.510	3.1×10^{-10}
3811.5	.01050	.525	3.1×10^{-10}
3884.2	.01070	.535	3.4×10^{-10}
3979.7	.01140	.570	3.1×10^{-10}
4051.3	.01145	.572	2.9×10^{-10}
4147.1	.01145	.572	2.9×10^{-10}
4218.3	.01145	.572	3.2×10^{-10}
4314.4	.01160	.580	3.1×10^{-10}
4386.5	.01165	.582	3.0×10^{-10}
4482.2	.01230	.615	2.9×10^{-10}
4554.1	.01225	.612	3.0×10^{-10}
4650.5	.01235	.618	3.2×10^{-10}
4724.0	.01240	.620	3.0×10^{-10}
4818.5	.01270	.635	3.3×10^{-10}
4890.2	.01290	.645	3.0×10^{-10}
5010.6	.01290	.645	3.2×10^{-10}
5058.3	.01300	.650	4.4×10^{-10}
5157.1	.01310	.655	3.0×10^{-10}
5226.0	.01340	.670	2.9×10^{-10}
5250.1	.01370	.685	2.8×10^{-10}
5324.2	.01375	.688	2.8×10^{-10}
5394.5	.01380	.690	2.8×10^{-10}
5490.3	.01395	.698	2.7×10^{-10}
5562.2	.01405	.702	2.8×10^{-10}
5658.7	.01420	.710	2.8×10^{-10}
5730.2	.01420	.710	2.8×10^{-10}
5850.2	.01460	.730	2.7×10^{-10}
5899.1	.01460	.730	2.7×10^{-10}
5994.6	.01500	.750	2.8×10^{-10}
6075.3	.01480	.740	2.5×10^{-10}
6162.3	.01480	.740	2.6×10^{-10}
6237.3	.01480	.740	2.6×10^{-10}
6333.6	.01480	.740	2.8×10^{-10}
6402.7	.01490	.745	2.8×10^{-10}
6499.1	.01495	.748	2.7×10^{-10}
6571.2	.01505	.752	2.7×10^{-10}
6666.5	.01520	.760	2.6×10^{-10}
6738.0	.01520	.760	2.5×10^{-10}
6834.3	.01525	.762	2.7×10^{-10}
6906.0	.01535	.766	2.7×10^{-10}

TABLE V (Continued)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
7004.4	.01550	.775	3.3×10^{-10}
7074.3	.01560	.780	2.6×10^{-10}
7170.1	.01595	.798	2.6×10^{-10}
7242.3	.01600	.800	2.5×10^{-10}
7362.8	.01605	.802	2.6×10^{-10}
7410.0	.01610	.805	2.6×10^{-10}
7506.6	.01620	.810	2.6×10^{-10}
7578.0	.01630	.815	2.5×10^{-10}
7674.8	.01650	.825	2.6×10^{-10}
7746.4	.01640	.820	2.6×10^{-10}
7842.2	.01670	.835	2.5×10^{-10}

Test in Progress
Specimen B-20

TABLE VI

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED 3000°F (1649°C)

FOR 1 HOUR, TESTED AT 1860°F (1016°C), 20,000 PSI (1.38 x 10^8 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute(s)	.00010	.005	3.2 x 10-9
2	.00000	.000	3.2 x 10-9
3	.00000	.000	3.2 x 10-9
4	.00010	.005	3.2 x 10-9
5	.00015	.008	3.2 x 10-9
6	.00010	.005	3.2 x 10-9
7	.00020	.010	3.2 x 10-9
8	.00015	.008	3.2 x 10-9
9	.00015	.008	3.2 x 10-9
10	.00020	.010	3.2 x 10-9
15	.00020	.010	3.2 x 10-9
30	.00015	.008	3.2 x 10-9
45	.00015	.008	3.2 x 10-9
60	.00020	.010	3.2 x 10-9
65.2 Hours	.00070	.035	2.6 x 10-9
89.1	.00085	.042	2.2 x 10-9
113.2	.00110	.055	2.1 x 10-9
137.4	.00135	.068	1.9 x 10-9
161.0	.00140	.070	2.0 x 10-9
233.1	.00160	.080	1.8 x 10-9
256.9	.00165	.082	1.8 x 10-9
281.1	.00160	.080	1.8 x 10-9
305.0	.00180	.090	1.8 x 10-9
329.3	.00195	.098	1.7 x 10-9
401.4	.00195	.098	1.8 x 10-9
425.0	.00200	.100	1.6 x 10-9
449.1	.00200	.100	1.6 x 10-9
473.3	.00210	.105	1.7 x 10-9
497.0	.00205	.102	1.9 x 10-9
571.4	.00205	.102	1.7 x 10-9
593.3	.00210	.105	1.7 x 10-9

TABLE VI (Continued)

Time	Length Change L (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
617.0	.00210	.105	1.7×10^{-9}
641.1	.00215	.108	1.7×10^{-9}
665.1	.00220	.110	1.5×10^{-9}
761.5	.00230	.115	1.5×10^{-9}
785.3	.00230	.115	1.6×10^{-9}
809.1	.00235	.118	1.6×10^{-9}
833.2	.00235	.118	1.6×10^{-9}
908.2	.00235	.118	1.7×10^{-9}
929.1	.00240	.120	1.6×10^{-9}
953.1	.00240	.120	1.6×10^{-9}
976.9	.00245	.122	1.5×10^{-9}
1001.0	.00240	.120	1.4×10^{-9}
1073.1	.00250	.125	1.6×10^{-9}
1097.0	.00250	.125	1.6×10^{-9}
1121.1	.00255	.128	1.5×10^{-9}
1145.4	.00265	.132	1.6×10^{-9}
1169.0	.00275	.138	1.5×10^{-9}
1241.2	.00280	.140	1.5×10^{-9}
1265.0	.00290	.145	1.5×10^{-9}
1289.1	.00300	.150	1.6×10^{-9}
1313.2	.00305	.152	1.7×10^{-9}
1337.3	.00300	.150	2.0×10^{-9}
1409.4	.00310	.155	1.6×10^{-9}
1433.4	.00315	.158	1.6×10^{-9}
1456.9	.00340	.170	1.6×10^{-9}
1481.1	.00350	.175	1.6×10^{-9}
1505.0	.00360	.180	1.4×10^{-9}
1601.4	.00380	.190	1.7×10^{-9}
1625.2	.00390	.195	1.5×10^{-9}
1649.8	.00395	.198	1.7×10^{-9}
1673.0	.00400	.200	1.6×10^{-9}
1745.4	.00435	.218	1.9×10^{-9}
1769.2	.00435	.218	1.9×10^{-9}
1795.2	.00435	.218	1.8×10^{-9}
1826.3	.00440	.220	1.8×10^{-9}
1841.2	.00450	.225	1.5×10^{-9}
1913.1	.00470	.235	1.0×10^{-9}
1937.1	.00470	.235	1.1×10^{-9}
1961.1	.00485	.242	1.0×10^{-9}
1988.3	.00485	.242	1.0×10^{-9}

TABLE VI (Continued)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
2010.0	.00500	.250	1.0×10^{-9}
2081.6	.00525	.262	1.4×10^{-9}
2105.7	.00535	.268	1.2×10^{-9}
2129.3	.00545	.272	1.6×10^{-9}
2153.5	.00550	.275	1.4×10^{-9}
2177.6	.00560	.280	1.1×10^{-9}
2249.7	.00600	.300	1.1×10^{-9}
2273.4	.00620	.310	1.1×10^{-9}
2297.4	.00640	.320	1.0×10^{-9}
2321.9	.00660	.330	1.1×10^{-9}
2346.1	.00665	.332	1.0×10^{-9}
2417.3	.00690	.345	1.3×10^{-9}
2441.5	.00690	.345	1.2×10^{-9}
2465.0	.00705	.352	1.2×10^{-9}
2488.9	.00715	.356	1.1×10^{-9}
2513.0	.00725	.362	1.1×10^{-9}
2585.2	.00750	.375	1.3×10^{-9}
2609.1	.00765	.382	1.1×10^{-9}
2632.8	.00790	.395	1.1×10^{-9}
2657.0	.00790	.395	1.1×10^{-9}
2680.7	.00790	.395	1.1×10^{-9}
2754.4	.00845	.422	1.3×10^{-9}
2776.9	.00870	.435	1.1×10^{-9}
2801.2	.00880	.440	1.0×10^{-9}
2825.2	.00880	.440	1.1×10^{-9}
2849.0	.00890	.445	1.1×10^{-9}
2921.0	.00940	.470	1.1×10^{-9}
2945.2	.00960	.480	1.2×10^{-9}
2969.2	.00970	.485	1.1×10^{-9}
2993.2	.00985	.492	1.1×10^{-9}
3017.1	.01000	.500	1.2×10^{-9}
3113.7	.01055	.528	1.0×10^{-9}
3137.2	.01060	.530	1.0×10^{-9}
3160.9	.01075	.538	1.1×10^{-9}
3185.0	.01095	.548	1.0×10^{-9}
3257.5	.01140	.570	1.1×10^{-9}
3281.1	.01150	.575	1.0×10^{-9}
3305.1	.01160	.580	1.0×10^{-9}
3328.9	.01175	.588	1.0×10^{-9}
3425.6	.01215	.608	1.0×10^{-9}
3473.2	.01250	.625	1.1×10^{-9}
3497.3	.01280	.640	1.1×10^{-9}
3521.0	.01285	.642	1.1×10^{-9}
3593.1	.01335	.668	1.1×10^{-9}

Test in Progress
Specimen S-24

TABLE VII

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 2300°F (1260°C), FOR 1 HOUR, TESTED AT 2000°F (1093°C), 28,000 PSI (1.93×10^8 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute(s)	.00005	.002	9.0×10^{-9}
2	.00005	.002	9.0×10^{-9}
3	.00000	.000	9.0×10^{-9}
4	.00000	.000	9.0×10^{-9}
5	.00005	.002	9.0×10^{-9}
6	.00005	.002	9.0×10^{-9}
7	.00000	.000	9.0×10^{-9}
8	.00005	.002	9.0×10^{-9}
9	.00010	.005	9.0×10^{-9}
10	.00005	.002	9.0×10^{-9}
15	.00005	.002	9.0×10^{-9}
30	.00000	.000	9.0×10^{-9}
45	.00000	.000	9.0×10^{-9}
60	.00000	.000	9.0×10^{-9}
17.3 Hours	.00155	.078	3.4×10^{-9}
25.2	.00170	.085	3.3×10^{-9}
40.8	.00175	.088	1.5×10^{-9}
65.9	.00245	.122	1.1×10^{-9}
88.9	.00290	.145	1.0×10^{-9}
161.5	.00390	.195	6.4×10^{-10}
185.0	.00410	.205	6.4×10^{-10}
209.1	.00425	.212	6.0×10^{-10}
238.5	.00480	.240	5.5×10^{-10}
257.0	.00485	.242	5.2×10^{-10}
329.6	.00530	.265	4.6×10^{-10}
352.2	.00555	.278	4.6×10^{-10}
376.0	.00580	.290	4.6×10^{-10}
400.0	.00590	.295	4.9×10^{-10}
424.4	.00600	.300	4.8×10^{-10}
496.2	.00635	.318	4.2×10^{-10}
520.1	.00645	.322	4.2×10^{-10}
544.6	.00660	.330	4.1×10^{-10}
568.3	.00670	.335	4.2×10^{-10}
591.9	.00685	.342	4.2×10^{-10}

TABLE VII (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
663.9	.00745	.372	3.7×10^{-10}
687.9	.00765	.382	3.7×10^{-10}
711.9	.00780	.390	3.8×10^{-10}
735.8	.00785	.392	3.6×10^{-10}
760.2	.00800	.400	3.4×10^{-10}
832.2	.00860	.430	3.6×10^{-10}
855.9	.00885	.442	3.9×10^{-10}
879.8	.00890	.445	3.6×10^{-10}
905.8	.00895	.448	3.6×10^{-10}
928.6	.00890	.445	4.8×10^{-10}
990.3	.00940	.470	3.2×10^{-10}
1014.1	.00955	.478	3.1×10^{-10}
1037.9	.00970	.485	3.6×10^{-10}
1061.9	.00980	.490	3.4×10^{-10}
1085.9	.00975	.488	3.0×10^{-10}
1182.3	.01030	.515	2.4×10^{-10}
1206.3	.01075	.538	2.1×10^{-10}
1230.0	.01075	.538	2.8×10^{-10}
1254.1	.01070	.535	2.0×10^{-10}
1328.9	.01100	.550	2.1×10^{-10}
1350.0	.01100	.550	2.0×10^{-10}
1373.9	.01110	.555	2.0×10^{-10}
1397.7	.01115	.558	2.0×10^{-10}
1421.8	.01135	.568	1.9×10^{-10}
1493.9	.01165	.582	1.8×10^{-10}
1517.8	.01170	.585	1.6×10^{-10}
1542.0	.01175	.588	1.8×10^{-10}
1566.3	.01190	.595	1.6×10^{-10}
1589.8	.01200	.600	1.6×10^{-10}
1662.0	.01250	.625	1.4×10^{-10}
1685.9	.01260	.630	1.4×10^{-10}
1710.0	.01265	.632	1.8×10^{-10}
1734.0	.01280	.640	1.3×10^{-10}

TABLE VII (Continued)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1759.7	.01285	.642	2.0×10^{-10}
1830.5	.01310	.655	1.9×10^{-10}
1854.2	.01330	.665	1.6×10^{-10}
1877.7	.01340	.670	1.8×10^{-10}
1902.0	.01345	.672	1.4×10^{-10}
1925.9	.01355	.678	1.7×10^{-10}
2021.9	.01390	.695	1.5×10^{-10}
2046.3	.01405	.702	1.8×10^{-10}
2070.9	.01430	.715	1.7×10^{-10}
2093.9	.01460	.730	1.5×10^{-10}
2166.3	.01520	.760	1.9×10^{-10}
2190.1	.01530	.765	1.6×10^{-10}
2216.0	.01540	.770	1.6×10^{-10}
2247.0	.01545	.772	1.5×10^{-10}
2262.0	.01550	.775	1.5×10^{-10}
2334.0	.01565	.782	1.4×10^{-10}
2357.9	.01570	.785	1.4×10^{-10}
2381.9	.01580	.790	1.2×10^{-10}
2409.1	.01600	.800	1.3×10^{-10}
2430.8	.01610	.805	1.4×10^{-10}
2502.6	.01690	.845	1.5×10^{-10}
2526.9	.01715	.858	1.5×10^{-10}
2550.8	.01745	.872	1.6×10^{-10}
2574.5	.01780	.890	1.6×10^{-10}
2598.5	.01805	.902	1.4×10^{-10}
2670.6	.01835	.918	1.3×10^{-10}
2694.3	.01850	.925	1.1×10^{-10}
2718.5	.01895	.948	1.4×10^{-10}
2743.1	.01880	.940	1.4×10^{-10}
2767.1	.01880	.940	1.2×10^{-10}
2838.3	.01890	.945	1.2×10^{-10}
2862.3	.01910	.955	1.2×10^{-10}
2885.8	.01930	.965	1.1×10^{-10}
2909.7	.01940	.970	1.1×10^{-10}
2933.8	.01960	.980	1.1×10^{-10}
3006.1	.01990	.995	1.1×10^{-10}
3029.9	.02015	1.006	1.1×10^{-10}
3053.7	.02030	1.015	1.1×10^{-10}
3077.6	.02045	1.022	1.2×10^{-10}
3101.5	.02045	1.022	1.1×10^{-10}
3176.2	.02020	1.010	1.2×10^{-10}
3197.8	.02030	1.015	1.1×10^{-10}
3222.0	.02035	1.018	1.0×10^{-10}

TABLE VII (Continued)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
3246.1	.02035	1.018	1.1×10^{-10}
3269.8	.02040	1.020	1.2×10^{-10}
3342.7	.02040	1.020	1.0×10^{-10}
3365.9	.02045	1.022	1.0×10^{-10}
3390.2	.02055	1.028	1.0×10^{-10}
3414.1	.02055	1.028	1.0×10^{-10}
3427.9	.02060	1.030	1.0×10^{-10}
3534.5	.02090	1.045	1.0×10^{-10}
3558.2	.02100	1.050	1.0×10^{-10}
3581.7	.02110	1.055	1.0×10^{-10}
3605.9	.02115	1.058	1.0×10^{-10}
3678.3	.02125	1.062	1.0×10^{-10}
3702.0	.02130	1.065	1.0×10^{-10}
3726.0	.02140	1.070	1.0×10^{-10}
3749.8	.02150	1.075	1.0×10^{-10}
3774.4	.02160	1.080	1.0×10^{-10}
3846.5	.02190	1.095	1.0×10^{-10}
3870.0	.02200	1.100	1.0×10^{-10}
3894.0	.02200	1.100	1.0×10^{-10}
3918.1	.02210	1.105	1.0×10^{-10}
3941.8	.02225	1.112	1.0×10^{-10}
4013.9	.02250	1.125	1.0×10^{-10}

Test in Progress
Specimen B-28

TABLE VIII

CREEP TEST DATA, STRESS RELIEVED TZM FORGED DISC, HEAT NO. 7502, TESTED AT 1800°F (982°C), 44,000 PSI (3.03×10^8 N/m^2)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute (s)	.00005	.002	1.2×10^{-8}
2	-.00005	-.002	1.2×10^{-8}
3	.00000	.000	1.2×10^{-8}
4	.00005	.002	1.2×10^{-8}
5	.00015	.008	1.2×10^{-8}
6	.00015	.008	1.2×10^{-8}
7	.00025	.012	1.2×10^{-8}
8	.00025	.012	1.2×10^{-8}
9	.00020	.010	1.2×10^{-8}
10	.00030	.015	1.2×10^{-8}
15	.00030	.015	1.2×10^{-8}
30	.00030	.015	1.2×10^{-8}
45	.00030	.015	1.2×10^{-8}
60	.00025	.012	1.2×10^{-8}
1.4 Hours	.00030	.015	1.3×10^{-8}
25.6	.00135	.068	3.6×10^{-9}
53.2	.00145	.072	3.0×10^{-9}
64.4	.00150	.075	3.1×10^{-9}
87.6	.00155	.078	3.1×10^{-9}
111.9	.00155	.078	2.8×10^{-9}
135.7	.00165	.082	2.9×10^{-9}
159.6	.00170	.085	2.8×10^{-9}
256.2	.00185	.092	2.8×10^{-9}
279.9	.00190	.095	3.0×10^{-9}
303.4	.00200	.100	3.1×10^{-9}
327.6	.00200	.100	3.1×10^{-9}
400.0	.00230	.115	2.7×10^{-9}
423.7	.00230	.115	2.7×10^{-9}
447.8	.00235	.118	2.7×10^{-9}
471.5	.00235	.118	3.0×10^{-9}
496.1	.00245	.122	2.8×10^{-9}
568.2	.00265	.132	2.6×10^{-9}
591.8	.00270	.135	2.6×10^{-9}
615.7	.00275	.138	2.6×10^{-9}
639.8	.00280	.140	2.7×10^{-9}
663.6	.00290	.145	2.6×10^{-9}
735.6	.00300	.150	2.6×10^{-9}

Test in Progress
Specimen B-35

TABLE IX

CREEP TEST DATA, T-111 SHEET, HEAT NO. 111-D-1670, ANNEALED AT 3000°F (1649°C) FOR 1 HOUR, TESTED AT 1800°F (982°C), 17,000 PSI (1.11×10^8 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute (s)	.00010	.005	5.2×10^{-8}
2	.00015	.008	5.2×10^{-8}
3	.00015	.008	5.2×10^{-8}
4	.00015	.008	5.2×10^{-8}
5	.00015	.008	5.2×10^{-8}
6	.00015	.008	5.2×10^{-8}
7	.00015	.008	5.2×10^{-8}
8	.00015	.008	5.2×10^{-8}
9	.00020	.010	5.2×10^{-8}
10	.00015	.008	5.2×10^{-8}
15	.00015	.008	5.2×10^{-8}
30	.00015	.008	5.2×10^{-8}
45	.00020	.010	5.2×10^{-8}
60	.00020	.010	5.2×10^{-8}
27.1 Hours	.00050	.025	1.5×10^{-8}
49.6	.00065	.032	1.2×10^{-8}
65.0	.00055	.028	6.4×10^{-9}
88.7	.00055	.028	4.6×10^{-9}
114.7	.00060	.030	3.0×10^{-9}
145.8	.00070	.035	2.4×10^{-9}
160.7	.00070	.035	2.0×10^{-9}
232.7	.00070	.035	1.7×10^{-9}
256.6	.00065	.032	1.6×10^{-9}
280.6	.00075	.038	1.4×10^{-9}
307.8	.00075	.038	1.4×10^{-9}
329.5	.00080	.040	1.3×10^{-9}
404.1	.00075	.038	1.5×10^{-9}
425.4	.00080	.040	1.4×10^{-9}
448.8	.00085	.042	1.4×10^{-9}
473.1	.00085	.042	1.3×10^{-9}
497.2	.00085	.042	1.1×10^{-9}
569.3	.00080	.040	9.4×10^{-9}
592.9	.00080	.040	9.2×10^{-10}
617.1	.00085	.042	8.8×10^{-10}
641.6	.00090	.045	8.8×10^{-10}
665.7	.00095	.048	8.6×10^{-10}
736.9	.00110	.055	8.2×10^{-10}
761.0	.00110	.055	8.2×10^{-10}
784.5	.00110	.055	7.9×10^{-10}
808.5	.00110	.055	7.8×10^{-10}
832.5	.00110	.055	7.7×10^{-10}
904.7	.00110	.055	7.7×10^{-10}
928.5	.00110	.055	7.5×10^{-10}
952.4	.00110	.055	7.5×10^{-10}
976.4	.00110	.055	7.2×10^{-10}

TABLE IX (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1000.2 Hours-	.00110	.055	7.0×10^{-10}
1074.0	.00110	.055	7.3×10^{-10}
1096.5	.00120	.060	6.8×10^{-10}
1120.7	.00120	.060	6.8×10^{-10}
1144.7	.00120	.060	6.9×10^{-10}
1168.5	.00115	.058	6.9×10^{-10}
1240.5	.00120	.060	6.6×10^{-10}
1264.7	.00115	.058	6.5×10^{-10}
1288.7	.00125	.062	6.5×10^{-10}
1312.7	.00125	.062	6.4×10^{-10}
1336.6	.00130	.065	6.2×10^{-10}
1433.2	.00145	.072	5.9×10^{-10}
1456.7	.00155	.078	6.1×10^{-10}
1480.4	.00155	.078	6.1×10^{-10}
1504.5	.00155	.078	6.0×10^{-10}
1577.0	.00160	.080	6.0×10^{-10}
1600.6	.00165	.082	7.1×10^{-10}
1624.6	.00165	.082	7.2×10^{-10}
1648.4	.00165	.082	7.0×10^{-10}
1673.1	.00170	.085	6.9×10^{-10}
1745.2	.00175	.088	5.4×10^{-10}
1768.7	.00180	.090	5.4×10^{-10}
1792.7	.00175	.088	5.4×10^{-10}
1816.8	.00190	.095	5.4×10^{-10}
1840.5	.00195	.098	5.4×10^{-10}
1912.6	.00200	.100	5.4×10^{-10}

Test in Progress
Specimen S-26

TABLE X

CREEP TEST DATA, TZM FORGED DISC, HEAT NO. 1175, TESTED AT 1800°F (982°C)

44,000 PSI ($3.03 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00000	.000	4.8×10^{-7}
2	.00010	.005	4.8×10^{-7}
3	.00020	.010	4.8×10^{-7}
4	.00025	.012	4.8×10^{-7}
5	.00015	.008	4.8×10^{-7}
6	.00015	.008	4.8×10^{-7}
7	.00010	.005	4.8×10^{-7}
8	.00015	.008	4.8×10^{-7}
9	.00020	.010	4.8×10^{-7}
10	.00020	.010	4.8×10^{-7}
15	.00020	.010	4.8×10^{-7}
30	.00025	.012	4.8×10^{-7}
45	.00025	.012	4.8×10^{-7}
60	.00030	.015	4.8×10^{-7}
65.5 hours	.00055	.028	3.0×10^{-7}
89.1	.00070	.035	2.8×10^{-7}
113.1	.00095	.048	1.1×10^{-8}
137.1	.00100	.050	2.1×10^{-8}
161.1	.00100	.050	1.7×10^{-9}
233.0	.00100	.050	1.0×10^{-9}
257.3	.00105	.052	8.4×10^{-10}
280.9	.00105	.052	1.3×10^{-9}
305.2	.00110	.055	1.6×10^{-9}
329.4	.00110	.055	1.4×10^{-9}
401.0	.00115	.058	1.4×10^{-9}
426.7	.00115	.058	4.0×10^{-10}
449.2	.00120	.060	5.8×10^{-10}
473.4	.00130	.065	7.6×10^{-10}
497.0	.00135	.068	3.8×10^{-10}
569.2	.00145	.072	3.9×10^{-10}
593.1	.00140	.070	5.5×10^{-10}
616.9	.00145	.072	8.4×10^{-10}
640.8	.00140	.070	7.8×10^{-10}
664.8	.00150	.075	5.0×10^{-10}

TABLE X (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure
736.8	.00150	.075	8.8 x 10-10
761.7	.00150	.075	8.6 x 10-10
785.0	.00150	.075	5.0 x 10-10
808.8	.00155	.078	9.0 x 10-10
833.8	.00155	.078	5.0 x 10-10
904.7	.00160	.080	8.4 x 10-10
928.8	.00160	.080	8.9 x 10-10
953.1	.00160	.080	7.0 x 10-10
977.0	.00165	.082	6.0 x 10-10
1001.0	.00180	.090	9.2 x 10-10
1073.0	.00180	.090	9.1 x 10-10
1144.9	.00175	.088	8.2 x 10-10
1240.7	.00175	.088	7.5 x 10-10
1313.2	.00180	.090	9.0 x 10-10
1409.5	.00180	.090	5.8 x 10-10
1484.2	.00180	.090	4.4 x 10-10
1577.2	.00185	.092	4.0 x 10-10
1650.2	.00185	.092	3.5 x 10-10
1743.9	.00190	.095	4.5 x 10-10
1822.5	.00200	.100	4.0 x 10-10
1913.6	.00215	.108	4.9 x 10-10
1984.0	.00210	.105	3.5 x 10-10
2080.1	.00215	.108	3.0 x 10-10
2152.2	.00215	.108	4.0 x 10-10
2247.9	.00220	.110	3.5 x 10-10
2319.8	.00225	.112	2.8 x 10-10
2416.7	.00235	.118	3.5 x 10-10
2489.7	.00230	.115	2.4 x 10-10
2584.3	.00235	.118	2.2 x 10-10
2655.9	.00240	.120	2.4 x 10-10
2776.3	.00250	.125	3.8 x 10-10
2824.8	.00250	.125	4.6 x 10-10
2922.9	.00250	.125	4.4 x 10-10
2991.8	.00245	.122	4.0 x 10-10
3015.8	.00245	.122	4.0 x 10-10
3088.0	.00245	.122	3.7 x 10-10
3160.4	.00245	.122	4.0 x 10-10
3256.0	.00250	.125	4.4 x 10-10
3328.7	.00255	.128	4.1 x 10-10

TABLE X (Continued)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
3424.5	.00255	.128	3.4×10^{-10}
3496.0	.00255	.128	4.5×10^{-10}
3615.9	.00260	.130	3.5×10^{-10}
3664.8	.00255	.128	3.5×10^{-10}
3760.4	.00255	.128	4.2×10^{-10}
3831.9	.00255	.128	3.5×10^{-10}
3928.0	.00255	.128	3.4×10^{-10}
4002.1	.00260	.130	3.9×10^{-10}
4096.6	.00260	.130	3.4×10^{-10}
4168.7	.00255	.128	4.0×10^{-10}
4265.1	.00265	.132	3.6×10^{-10}
4338.1	.00270	.135	3.1×10^{-10}
4432.3	.00260	.130	3.2×10^{-10}
4503.7	.00270	.135	3.5×10^{-10}
4600.0	.00290	.145	2.6×10^{-10}
4671.7	.00270	.135	3.5×10^{-10}
4770.2	.00270	.135	3.6×10^{-10}
4840.1	.00275	.138	3.5×10^{-10}
4936.8	.00275	.138	3.9×10^{-10}
5008.0	.00280	.140	3.8×10^{-10}
5128.5	.00285	.142	3.2×10^{-10}
5175.7	.00290	.145	3.0×10^{-10}
5275.4	.00290	.145	3.0×10^{-10}
5343.8	.00290	.145	3.5×10^{-10}
5440.5	.00290	.145	3.0×10^{-10}
5512.1	.00295	.148	3.0×10^{-10}
5607.9	.00295	.148	3.2×10^{-10}

Test in Progress
Specimen B-25

TABLE XI

CREEP TEST DATA, T-111, HEAT NO. 1102, ANNEALED AT 3000°F (1649°C) FOR 1 HOUR, TESTED AT 2000°F (1093°C), 13,000 PSI (8.96×10^{-7} N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute (s)	.00010	.005	1.1×10^{-8}
2	.00000	.000	1.1×10^{-8}
3	.00010	.005	1.1×10^{-8}
4	.00005	.002	1.1×10^{-8}
5	.00015	.008	1.1×10^{-8}
6	.00015	.008	1.1×10^{-8}
7	.00015	.008	1.1×10^{-8}
8	.00020	.010	1.1×10^{-8}
9	.00015	.008	1.1×10^{-8}
10	.00015	.008	1.1×10^{-8}
15	.00020	.010	1.1×10^{-8}
30	.00015	.008	1.1×10^{-8}
45	.00015	.008	1.1×10^{-8}
60	.00020	.010	1.1×10^{-8}
1.5 Hours	.00020	.010	1.0×10^{-8}
18.1	.00080	.040	8.9×10^{-9}
114.4	.00150	.075	4.1×10^{-9}
138.2	.00165	.082	4.0×10^{-9}
161.9	.00210	.105	3.8×10^{-9}
186.0	.00205	.102	3.5×10^{-9}
258.4	.00250	.125	3.3×10^{-9}
282.1	.00270	.135	3.3×10^{-9}
306.1	.00280	.140	3.1×10^{-9}
330.0	.00310	.155	3.0×10^{-9}
354.6	.00330	.165	2.9×10^{-9}
426.7	.00415	.208	2.8×10^{-9}
450.2	.00440	.220	2.8×10^{-9}
474.2	.00470	.235	2.8×10^{-9}
498.3	.00490	.245	2.7×10^{-9}
522.1	.00495	.248	2.8×10^{-9}
594.1	.00555	.278	2.4×10^{-9}

Test In Progress
Specimen S-27

TABLE XII

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 2500°F (1371°C) FOR 1 HOUR TESTED AT 1935°F (1057°C), 20,000 PSI (1.38×10^8 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute(s)	.00000	.000	2.0×10^{-8}
2	-.00005	-.002	2.0×10^{-8}
3	-.00010	-.005	2.0×10^{-8}
4	-.00010	-.005	2.0×10^{-8}
5	-.00010	-.005	2.0×10^{-8}
6	-.00015	-.008	2.0×10^{-8}
7	-.00015	-.008	2.0×10^{-8}
8	-.00020	-.010	2.0×10^{-8}
9	-.00015	-.008	2.0×10^{-8}
10	-.00015	-.008	2.0×10^{-8}
15	-.00010	-.005	2.0×10^{-8}
30	-.00030	-.015	2.0×10^{-8}
45	-.00030	-.015	2.0×10^{-8}
60	-.00025	-.012	2.0×10^{-8}
16.8 Hours	.00015	.008	1.1×10^{-8}
91.2	.00080	.040	2.7×10^{-9}
113.1	.00100	.050	2.2×10^{-9}
136.1	.00105	.052	2.0×10^{-9}
160.9	.00105	.052	1.7×10^{-9}
184.9	.00115	.058	1.6×10^{-9}
281.3	.00120	.060	5.2×10^{-10}
305.1	.00120	.060	5.1×10^{-10}
328.9	.00125	.062	5.1×10^{-10}
353.0	.00130	.065	5.3×10^{-10}
428.0	.00170	.085	4.8×10^{-10}
448.9	.00180	.090	4.6×10^{-10}
472.8	.00185	.092	1.2×10^{-9}
496.7	.00185	.092	4.7×10^{-10}
520.7	.00185	.092	1.1×10^{-9}
592.9	.00190	.095	9.5×10^{-10}
616.8	.00190	.095	9.8×10^{-10}
640.9	.00190	.095	9.5×10^{-10}
665.2	.00195	.098	9.8×10^{-10}
688.8	.00190	.095	9.8×10^{-10}
761.0	.00200	.100	9.2×10^{-10}
784.8	.00195	.098	9.2×10^{-10}
808.9	.00195	.098	9.8×10^{-10}
833.0	.00200	.100	1.1×10^{-9}

TABLE XII (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
857.1 (Hours)	.00195	.098	1.4×10^{-9}
929.2	.00210	.105	9.0×10^{-10}
953.1	.00210	.105	7.8×10^{-10}
976.7	.00220	.110	8.3×10^{-10}
1000.9	.00215	.108	8.8×10^{-10}
1024.9	.00230	.115	7.9×10^{-10}
1120.9	.00235	.118	8.1×10^{-10}
1145.0	.00235	.118	7.4×10^{-10}
1169.6	.00230	.115	7.2×10^{-10}
1192.8	.00230	.115	7.1×10^{-10}
1265.2	.00235	.118	8.0×10^{-10}
1346.1	.00250	.125	7.2×10^{-10}
1432.9	.00255	.128	5.6×10^{-10}
1508.1	.00260	.130	5.5×10^{-10}
1604.4	.00250	.125	7.2×10^{-10}
1673.4	.00270	.135	6.3×10^{-10}
1769.5	.00280	.140	4.7×10^{-10}
1841.8	.00280	.140	4.7×10^{-10}
1937.1	.00290	.145	4.6×10^{-10}
2008.7	.00300	.150	4.5×10^{-10}
2105.0	.00300	.150	5.2×10^{-10}
2176.6	.00300	.150	4.2×10^{-10}
2274.3	.00340	.170	4.7×10^{-10}
2345.0	.00385	.192	4.2×10^{-10}
2440.8	.00380	.190	4.0×10^{-10}
2513.0	.00385	.192	4.4×10^{-10}
2633.5	.00380	.190	3.6×10^{-10}
2680.6	.00380	.190	3.8×10^{-10}
2777.3	.00385	.192	4.2×10^{-10}
2848.7	.00385	.192	3.5×10^{-10}
2945.4	.00385	.192	3.3×10^{-10}
3017.1	.00390	.195	3.6×10^{-10}
3112.9	.00395	.198	3.4×10^{-10}

Test in Progress
Specimen B-32

TABLE XIII

CREEP TEST DATA, TZC PLATE, HEAT NO M-91, ANNEALED AT 2500°F (1371°C) FOR 1 HOUR, TESTED AT 1900°F (1038°C), 22,000 PSI (1.52×10^8 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute(s)	-.00005	-.002	9.7×10^{-9}
2	-.00005	-.002	9.7×10^{-9}
3	-.00010	-.005	9.7×10^{-9}
4	.00005	.002	9.7×10^{-9}
5	.00005	.002	9.7×10^{-9}
6	.00005	.002	9.7×10^{-9}
7	.00005	.002	9.7×10^{-9}
8	.00010	.005	9.7×10^{-9}
9	.00010	.005	9.7×10^{-9}
10	.00010	.005	9.7×10^{-9}
15	.00015	.008	9.7×10^{-9}
30	.00020	.010	9.7×10^{-9}
45	.00020	.010	9.7×10^{-9}
60	.00030	.015	9.7×10^{-9}
17.2 Hours	.00065	.032	5.2×10^{-9}
41.3	.00115	.058	3.7×10^{-9}
44.2	.00120	.060	3.7×10^{-9}
70.1	.00180	.090	3.2×10^{-9}
98.5	.00195	.098	2.6×10^{-9}
116.1	.00200	.100	2.5×10^{-9}
137.2	.00200	.100	2.2×10^{-9}
161.1	.00205	.102	1.8×10^{-9}
184.9	.00210	.105	1.7×10^{-9}
209.0	.00205	.102	1.7×10^{-9}
281.1	.00240	.120	1.6×10^{-9}
305.0	.00245	.122	1.5×10^{-9}
329.2	.00250	.125	1.4×10^{-9}
353.4	.00270	.135	1.3×10^{-9}
377.0	.00275	.138	1.1×10^{-9}
449.1	.00285	.142	1.0×10^{-9}
473.0	.00295	.148	1.0×10^{-9}
497.1	.00300	.150	1.2×10^{-9}
521.9	.00310	.155	1.3×10^{-9}
546.8	.00310	.155	1.5×10^{-9}
617.7	.00315	.158	1.4×10^{-9}
641.3	.00320	.160	1.2×10^{-9}
664.8	.00325	.162	1.2×10^{-9}
689.1	.00335	.168	1.2×10^{-9}
713.0	.00340	.170	6.4×10^{-10}
809.1	.00350	.175	9.6×10^{-10}
833.4	.00355	.178	9.7×10^{-10}
858.0	.00360	.180	9.5×10^{-10}
881.1	.00365	.182	9.2×10^{-10}
953.4	.00375	.188	8.3×10^{-10}
977.3	.00380	.190	9.2×10^{-10}

TABLE XIII (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1003.2	.00380	.190	9.1×10^{-10}
1034.2	.00380	.190	8.8×10^{-10}
1049.2	.00375	.188	8.5×10^{-10}
1121.2	.00390	.195	7.9×10^{-10}
1145.0	.00385	.192	8.2×10^{-10}
1169.1	.00390	.195	7.8×10^{-10}
1195.4	.00390	.195	7.5×10^{-10}
1218.0	.00400	.200	3.5×10^{-10}
1289.8	.00425	.212	6.6×10^{-10}
1314.0	.00430	.215	7.3×10^{-10}
1337.9	.00430	.215	6.9×10^{-10}
1361.8	.00435	.218	4.1×10^{-10}
1385.7	.00445	.222	6.4×10^{-10}
1458.1	.00460	.230	3.2×10^{-10}
1481.5	.00470	.235	3.5×10^{-10}
1505.8	.00470	.235	7.1×10^{-10}
1531.0	.00475	.238	7.0×10^{-10}
1554.2	.00480	.240	6.6×10^{-10}
1625.3	.00470	.235	6.9×10^{-10}
1649.5	.00470	.235	3.1×10^{-10}
1673.1	.00485	.242	6.6×10^{-10}
1696.3	.00490	.245	6.6×10^{-10}
1720.9	.00490	.245	6.4×10^{-10}
1793.2	.00480	.240	6.6×10^{-10}
1817.0	.00495	.246	3.0×10^{-10}
1840.8	.00510	.255	6.4×10^{-10}
1864.9	.00520	.260	6.3×10^{-10}
1888.7	.00520	.260	6.2×10^{-10}
1963.3	.00525	.262	6.5×10^{-10}
1984.9	.00535	.268	2.6×10^{-10}
2009.2	.00535	.268	6.0×10^{-10}
2033.3	.00540	.270	6.4×10^{-10}
2056.9	.00555	.278	6.7×10^{-10}
2129.9	.00570	.285	7.2×10^{-10}
2153.1	.00565	.282	6.8×10^{-10}
2177.4	.00570	.285	7.0×10^{-10}
2201.2	.00580	.290	7.0×10^{-10}
2225.1	.00580	.290	5.8×10^{-10}
2321.7	.00590	.295	6.4×10^{-10}
2345.3	.00585	.292	6.4×10^{-10}
2368.9	.00585	.292	5.7×10^{-10}
2393.0	.00590	.295	6.8×10^{-10}
2465.5	.00585	.292	6.6×10^{-10}
2489.2	.00585	.292	6.8×10^{-10}
2513.2	.00590	.295	6.4×10^{-10}
2536.9	.00590	.295	6.6×10^{-10}
2561.6	.00590	.295	6.4×10^{-10}
2633.7	.00595	.298	6.1×10^{-10}
2657.2	.00595	.298	6.2×10^{-10}

TABLE XIII (Continued)

Time	Length Change Δ L (inch) (2" G. L.)	Creep (%(	Pressure (Torr)
2681.2	.00595	.298	6.2×10^{-10}
2705.3	.00600	.300	6.4×10^{-10}
2729.0	.00605	.302	6.3×10^{-10}
2801.0	.00605	.302	6.3×10^{-10}

Test in Progress
Specimen B-33

TABLE XIV

CREEP TEST DATA, TZM COMMERCIAL BAR, HEAT NO. 7463, STRESS RELIEVED 0.5 HOUR AT 2250°F (1232°C) TESTED AT 2000°F (1093°C), 41,000 PSI (2.82×10^{-8} N/m^2)

Time	Length Change ΔL(inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute(s)	-.00005	-.002	2.4×10^{-8}
2	-.00010	-.005	2.4×10^{-8}
3	-.00015	-.008	2.4×10^{-8}
4	-.00010	-.005	2.4×10^{-8}
5	-.00010	-.005	2.4×10^{-8}
6	-.00010	-.005	2.4×10^{-8}
7	-.00010	-.005	2.4×10^{-8}
8	-.00015	-.008	2.4×10^{-8}
9	-.00015	-.008	2.4×10^{-8}
10	-.00010	-.005	2.4×10^{-8}
15	-.00015	-.008	2.4×10^{-8}
30	-.00005	-.002	2.4×10^{-8}
45	-.00005	-.002	2.4×10^{-8}
60	.00005	.002	2.4×10^{-8}
18.5 Hours	.00110	.055	2.7×10^{-9}
24.8	.00160	.080	3.0×10^{-9}
50.9	.00260	.130	1.4×10^{-9}
74.7	.00235	.118	9.7×10^{-10}
88.6	.00285	.142	1.0×10^{-9}
96.7	.00320	.160	1.0×10^{-9}
113.0	.00335	.168	9.4×10^{-10}
120.5	.00340	.170	9.5×10^{-10}
136.5	.00365	.182	8.8×10^{-10}
144.8	.00375	.188	8.0×10^{-10}
160.7	.00400	.200	6.4×10^{-10}
168.0	.00405	.202	6.3×10^{-10}
184.7	.00410	.205	8.0×10^{-10}
280.7	.00495	.248	5.5×10^{-10}
305.1	.00520	.260	5.5×10^{-10}
329.7	.00540	.270	5.4×10^{-10}
352.8	.00565	.282	5.4×10^{-10}
425.2	.00600	.300	5.9×10^{-10}
448.9	.00640	.320	5.4×10^{-10}
474.9	.00660	.330	5.3×10^{-10}
505.8	.00675	.338	4.9×10^{-10}
520.8	.00685	.342	5.0×10^{-10}
592.8	.00760	.380	5.0×10^{-10}
616.7	.00785	.392	5.0×10^{-10}
640.7	.00815	.408	4.7×10^{-10}
667.1	.00855	.428	4.8×10^{-10}
689.7	.00885	.442	5.0×10^{-10}
761.4	.00960	.480	5.5×10^{-10}
785.7	.00975	.488	5.4×10^{-10}
809.6	.01025	.512	7.3×10^{-10}
883.5	.01065	.532	5.0×10^{-10}
857.3	.01105	.552	5.2×10^{-10}
929.8	.01230	.615	4.9×10^{-10}

TABLE XIV (Continued)

Time	Length Change Δ L (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
953.1	.0.260	.630	4.7×10^{-10}
977.5	.01315	.658	4.9×10^{-10}
1002.7	.01345	.672	4.9×10^{-10}
1026.0	.01380	.690	4.5×10^{-10}
1097.1	.01560	.780	4.9×10^{-10}
1121.1	.01615	.806	4.8×10^{-10}
1144.7	.01685	.842	4.8×10^{-10}
1168.5	.01755	.876	4.8×10^{-10}
1192.6	.01835	.916	4.7×10^{-10}
1264.8	.02140	1.070	7.0×10^{-10}
1288.7	.02245	1.122	4.9×10^{-10}
1312.5	.02365	1.182	4.8×10^{-10}
1336.5	.02500	1.250	4.8×10^{-10}
1360.3	.02625	1.312	4.6×10^{-10}
1435.0	.03235	1.618	5.4×10^{-10}
1440.7	.03315	1.658	5.4×10^{-10}

Test Terminated - 1% Creep
Specimen B-34

TABLE XV

CREEP TEST DATA, T-111 SHEET, HEAT NO. LLL-D-1670, ANNEALED 3000°F (1649°C) FOR 1 HOUR TESTED AT 2000°F (1093°C), 15,000 PSI (1.03×10^{-8} N/m^2)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 Minute(s)	.00010	.005	1.7×10^{-8}
2	.00020	.010	1.7×10^{-8}
3	.00030	.015	1.7×10^{-8}
4	.00035	.018	1.7×10^{-8}
5	.00040	.020	1.7×10^{-8}
6	.00035	.018	1.7×10^{-8}
7	.00040	.020	1.7×10^{-8}
8	.00035	.018	1.7×10^{-8}
9	.00035	.018	1.7×10^{-8}
10	.00030	.015	1.7×10^{-8}
15	.00040	.020	1.7×10^{-8}
30	.00030	.015	1.7×10^{-8}
45	.00035	.018	1.7×10^{-8}
60	.00035	.018	1.7×10^{-8}
26.2 Hours	.00055	.028	4.8×10^{-9}
49.7	.00065	.032	2.2×10^{-9}
63.4	.00095	.048	2.0×10^{-9}
87.3	.00110	.055	1.3×10^{-9}
111.4	.00130	.065	1.5×10^{-9}
135.4	.00155	.078	2.0×10^{-9}
159.5	.00185	.092	2.1×10^{-9}
231.6	.00285	.142	1.2×10^{-9}
255.6	.00320	.160	1.1×10^{-9}
279.1	.00360	.180	1.1×10^{-9}
303.4	.00375	.188	1.0×10^{-9}
327.3	.00405	.202	9.8×10^{-10}
423.3	.00510	.255	6.2×10^{-10}
447.4	.00550	.275	8.5×10^{-10}
472.1	.00590	.295	8.6×10^{-10}
495.3	.00630	.315	8.2×10^{-10}
567.6	.00785	.392	7.8×10^{-10}
591.4	.00850	.425	7.8×10^{-10}
617.4	.00885	.442	6.3×10^{-10}
648.6	.00950	.475	7.8×10^{-10}
663.4	.00965	.482	7.4×10^{-10}
735.4	.01025	.512	7.5×10^{-10}
759.3	.01040	.520	7.4×10^{-10}
783.4	.01125	.562	7.4×10^{-10}
810.6	.01145	.572	7.4×10^{-10}
832.2	.01155	.578	7.3×10^{-10}
903.9	.01255	.628	7.2×10^{-10}
927.6	.01350	.675	5.4×10^{-10}
951.4	.01360	.680	2.0×10^{-9}
975.7	.01370	.685	6.9×10^{-10}
999.7	.01385	.692	5.5×10^{-10}

TABLE XV (Continued)

Time	Length Change Δ L (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1071.8 Hours	.01470	.735	6.8×10^{-10}
1095.7	.01490	.745	6.8×10^{-10}
1119.6	.01560	.780	6.6×10^{-10}
1143.9	.01625	.812	6.7×10^{-10}
1168.2	.01695	.848	6.6×10^{-10}
1239.5	.01760	.880	6.6×10^{-10}
1263.7	.01860	.930	6.6×10^{-10}
1287.2	.01920	.960	6.4×10^{-10}
1311.2	.01970	.985	6.5×10^{-10}
1335.2	.01995	.996	6.5×10^{-10}
1407.5	.02150	1.075	8.6×10^{-10}
1431.3	.02195	1.096	1.5×10^{-9}
1455.1	.02250	1.125	1.4×10^{-9}
1479.2	.02285	1.142	1.3×10^{-9}
1502.9	.02335	1.166	6.4×10^{-10}
1576.4	.02410	1.205	6.6×10^{-10}
1583.5	.02420	1.210	6.6×10^{-10}

Test Terminated - 1% Creep
Specimen S-25

TABLE XVI

CREEP TEST DATA, T-111 SHEET, HEAT NO. T-111-D-1670, ANNEALED AT 3000°F (1649°C) FOR 1 HOUR, TESTED AT 2600°F (1426°C), 1,500 PSI (1.03×10^7 N/m^2)

Time	Length Change L (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute (s)	.00000	.000	7.6×10^{-8}
2	.00000	.000	7.6×10^{-8}
3	.00005	.002	7.6×10^{-8}
4	.00005	.002	7.6×10^{-8}
5	.00005	.002	7.6×10^{-8}
6	.00005	.002	7.6×10^{-8}
7	.00010	.005	7.6×10^{-8}
8	.00010	.005	7.6×10^{-8}
9	.00010	.005	7.6×10^{-8}
10	.00010	.005	7.6×10^{-8}
15	.00010	.005	7.6×10^{-8}
30	.00010	.005	7.6×10^{-8}
45	.00005	.002	7.6×10^{-8}
60	.00010	.005	7.6×10^{-8}
1.7 Hours	.00010	.005	5.9×10^{-8}
17.5	.00160	.080	3.5×10^{-8}
25.7	.00200	.100	3.5×10^{-8}
89.5	.00515	.258	9.5×10^{-9}
97.6	.00560	.280	9.0×10^{-9}
113.7	.00655	.328	8.2×10^{-9}
121.1	.00690	.345	8.0×10^{-9}
137.7	.00720	.360	7.9×10^{-9}
145.9	.00740	.370	7.8×10^{-9}
161.8	.00820	.410	6.6×10^{-9}
169.6	.00830	.415	6.0×10^{-9}
185.6	.00880	.440	6.0×10^{-9}
194.6	.00900	.450	6.0×10^{-9}
213.8	.00960	.480	5.6×10^{-9}
239.8	.00975	.488	3.4×10^{-9}
260.4	.01005	.502	4.8×10^{-9}
281.6	.01025	.512	4.6×10^{-9}
289.9	.01045	.522	4.6×10^{-9}
305.7	.01060	.530	4.8×10^{-9}
329.4	.01080	.540	4.9×10^{-9}
353.6	.01090	.545	4.7×10^{-9}
361.9	.01105	.552	4.6×10^{-9}
380.3	.01125	.562	4.5×10^{-9}
407.2	.01140	.570	4.0×10^{-9}
425.8	.01185	.592	4.2×10^{-9}
449.6	.01225	.612	4.0×10^{-9}
473.6	.01255	.628	4.0×10^{-9}
481.7	.01265	.632	4.0×10^{-9}

Test Terminated
Specimen S-25A

TABLE XVII

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED 3000°F (1649°C) FOR 1 HOUR

TESTED AT 2200°F (1204°C), 8,000 PSI ($5.52 \times 10^7 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00005	.002	2.6×10^{-9}
2	.00010	.005	2.6×10^{-9}
3	.00015	.008	2.6×10^{-9}
4	.00010	.005	2.6×10^{-9}
5	.00005	.002	2.6×10^{-9}
6	.00005	.002	2.6×10^{-9}
7	.00005	.002	2.6×10^{-9}
8	.00000	.000	2.6×10^{-9}
9	.00005	.002	2.6×10^{-9}
10	.00005	.002	2.6×10^{-9}
15	.00000	.000	2.6×10^{-9}
30	.00010	.005	2.6×10^{-9}
45	.00010	.005	2.6×10^{-9}
60	.00005	.002	2.6×10^{-9}
2.4 hours	.00005	.002	2.6×10^{-9}
19.2	.00010	.005	2.0×10^{-9}
43.1	.00010	.005	1.6×10^{-9}
48.3	.00035	.018	1.6×10^{-9}
67.1	.00060	.030	1.5×10^{-9}
139.4	.00135	.068	1.4×10^{-9}
163.0	.00155	.078	1.4×10^{-9}
187.0	.00175	.088	1.2×10^{-9}
211.3	.00190	.095	1.3×10^{-9}
310.5	.00215	.108	1.2×10^{-9}
383.3	.00245	.122	1.3×10^{-9}
474.9	.00320	.160	1.3×10^{-9}
499.3	.00370	.185	1.2×10^{-9}
523.1	.00390	.195	1.3×10^{-9}
547.6	.00405	.202	1.2×10^{-9}
572.0	.00470	.235	1.3×10^{-9}
643.8	.00530	.265	1.4×10^{-9}
691.2	.00545	.272	1.3×10^{-9}
714.9	.00560	.280	1.2×10^{-9}
739.2	.00565	.282	1.2×10^{-9}
811.1	.00625	.312	1.3×10^{-9}
835.0	.00640	.320	1.2×10^{-9}
859.1	.00655	.328	1.4×10^{-9}
883.5	.00675	.338	1.3×10^{-9}

TABLE XVII (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
907.3 Hours	.00685	.342	1.3×10^{-9}
979.7	.00750	.375	1.3×10^{-9}
1051.4	.00835	.418	1.2×10^{-9}
1147.3	.00975	.488	1.3×10^{-9}
1219.0	.01050	.525	1.3×10^{-9}
1315.7	.01125	.562	1.1×10^{-9}
1387.2	.01150	.575	1.1×10^{-9}
1483.1	.01375	.688	8.3×10^{-9}
1555.3	.01410	.705	1.3×10^{-9}
1651.0	.01515	.758	7.0×10^{-10}
1723.4	.01615	.808	8.2×10^{-10}
1819.2	.01755	.878	9.0×10^{-10}
1890.9	.01830	.915	7.4×10^{-10}
1986.9	.01980	.990	7.9×10^{-10}
2059.0	.02080	1.040	8.3×10^{-10}
2154.8	.02230	1.115	7.0×10^{-10}
2227.1	.02315	1.158	6.9×10^{-10}
2323.1	.02445	1.222	7.5×10^{-10}
2395.0	.02580	1.290	7.0×10^{-10}
2490.8	.02700	1.350	7.2×10^{-10}
2563.3	.02780	1.390	7.0×10^{-10}
2659.6	.02970	1.485	7.3×10^{-10}
2734.4	.03080	1.540	7.4×10^{-10}
2827.3	.03205	1.602	6.6×10^{-10}
2900.0	.03320	1.660	6.5×10^{-10}
2923.0	.03345	1.672	6.7×10^{-10}
2995.6	.03505	1.752	6.5×10^{-10}
3018.9	.03530	1.765	6.6×10^{-10}
3043.2	.03560	1.780	6.6×10^{-10}
3072.1	.03670	1.835	6.6×10^{-10}
3091.1	.03635	1.818	6.8×10^{-10}
3162.9	.03745	1.872	6.5×10^{-10}
3186.2	.03750	1.875	6.4×10^{-10}
3210.1	.03820	1.910	6.5×10^{-10}
3234.1	.03910	1.955	6.8×10^{-10}
3258.5	.03940	1.970	6.8×10^{-10}
3330.3	.04025	2.012	6.4×10^{-10}
3354.0	.04050	2.025	6.6×10^{-10}
3378.7	.04085	2.042	6.6×10^{-10}
3402.3	.04120	2.060	6.4×10^{-10}
3426.0	.04155	2.078	6.4×10^{-10}
3498.0	.04300	2.150	6.6×10^{-10}
3522.0	.04320	2.160	6.7×10^{-10}
3546.0	.04350	2.175	7.0×10^{-10}
3569.0	.04420	2.210	6.6×10^{-10}
3594.3	.04465	2.232	6.2×10^{-10}
3666.3	.04585	2.292	7.0×10^{-10}

TABLE XVII (Continued)

Time	Length Change ΔL(inch) (2" G.L.)	Creep (%)	Pressure (Torr)
3689.9 Hours	.04620	2.310	6.4×10^{-10}
3713.9	.04660	2.330	6.8×10^{-10}
3738.2	.04710	2.355	6.6×10^{-10}
3762.0	.04750	2.375	6.8×10^{-10}
3834.4	.04870	2.435	6.6×10^{-10}
3858.2	.04905	2.452	6.4×10^{-10}
3882.0	.04935	2.468	6.5×10^{-10}
3906.0	.04985	2.492	6.4×10^{-10}
3930.0	.05040	2.520	6.3×10^{-10}
4026.4	.05215	2.608	6.2×10^{-10}
4050.2	.05230	2.615	6.5×10^{-10}
4074.1	.05295	2.648	6.2×10^{-10}
4098.1	.05330	2.665	6.4×10^{-10}
4173.0	.05430	2.715	6.3×10^{-10}
4194.0	.05495	2.748	6.2×10^{-10}
4218.0	.05540	2.770	6.1×10^{-10}
4241.9	.05580	2.790	6.2×10^{-10}
4265.9	.05625	2.812	6.4×10^{-10}
4338.0	.05745	2.872	6.0×10^{-10}
4362.0	.05790	2.895	5.9×10^{-10}
4386.1	.05860	2.930	5.9×10^{-10}
4410.3	.05905	2.952	6.3×10^{-10}
4433.9	.05935	2.968	6.1×10^{-10}
4506.1	.06045	3.022	6.2×10^{-10}
4530.0	.06100	3.050	6.1×10^{-10}
4554.0	.06160	3.080	6.2×10^{-10}
4578.1	.06195	3.098	6.2×10^{-10}
4602.4	.06215	3.108	7.1×10^{-10}
4674.5	.06320	3.160	7.4×10^{-10}
4698.3	.06365	3.182	7.2×10^{-10}
4721.8	.06425	3.212	7.3×10^{-10}
4746.0	.06485	3.242	7.6×10^{-10}
4770.0	.06525	3.262	7.4×10^{-10}
4866.0	.06735	3.368	7.6×10^{-10}
4869.5	.06735	3.368	7.6×10^{-10}

Test Terminated - 3% Creep
Specimen S-19

TABLE XVIII

CREEP TEST DATA T-111 SHEET, HEAT NO. T-111-D-1670, ANNEALED AT 3000°F (1649°C) FOR 1 HOUR, TESTED AT 2600°F (1426°C) 500 PSI (3.44×10^6 N/m^2)

Time	Length Change L (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 Minute (s)	.00005	.002	2.6×10^{-8}
2	.00005	.002	2.6×10^{-8}
3	.00000	.000	2.6×10^{-8}
4	.00005	.002	2.6×10^{-8}
5	.00000	.000	2.6×10^{-8}
6	.00005	.002	2.6×10^{-8}
7	.00005	.002	2.6×10^{-8}
8	.00005	.002	2.6×10^{-8}
9	.00010	.005	2.6×10^{-8}
10	.00005	.002	2.6×10^{-8}
15	-.00005	-.002	2.6×10^{-8}
30	-.00010	-.005	2.6×10^{-8}
45	-.00010	-.005	2.6×10^{-8}
60	-.00010	-.005	2.6×10^{-8}
16.4 Hours	-.00010	-.005	1.6×10^{-8}
40.4	.00005	.002	8.0×10^{-9}
64.4	.00050	.025	8.4×10^{-9}
83.3	.00075	.038	7.9×10^{-9}
160.3	.00180	.090	5.5×10^{-9}

Test in Progress
Specimen S-28

TABLE XIX

CREEP TEST DATA, VAPOR DEPOSITED TUNGSTEN, RECRYSTALLIZED 1 HOUR 2800°F (1538°C)

TESTED AT 2800°F (1538°C), 2000 PSI ($1.38 \times 10^7 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00020	.010	3.5×10^{-7}
2	.00025	.012	3.5×10^{-7}
3	.00025	.012	3.5×10^{-7}
4	.00025	.012	3.5×10^{-7}
5	.00025	.012	3.5×10^{-7}
6	.00030	.015	3.5×10^{-7}
7	.00040	.020	3.5×10^{-7}
8	.00035	.018	3.5×10^{-7}
9	.00040	.020	3.5×10^{-7}
10	.00035	.018	3.5×10^{-7}
15	.00000	.000	3.5×10^{-7}
30	-.00005	-.002	3.5×10^{-7}
45	.00000	.000	3.5×10^{-7}
60	-.00005	-.002	3.5×10^{-7}
64.9 hours	.00175	.088	8.0×10^{-8}
88.9	.00210	.105	6.4×10^{-8}
112.8	.00260	.130	4.6×10^{-8}
136.7	.00310	.155	4.1×10^{-8}
161.0	.00370	.185	3.8×10^{-8}
232.8	.00480	.240	3.4×10^{-8}
256.8	.00525	.262	3.1×10^{-8}
280.8	.00550	.275	2.9×10^{-8}
304.8	.00570	.285	2.7×10^{-8}
328.7	.00635	.318	2.6×10^{-8}
400.8	.00750	.375	1.6×10^{-8}
425.0	.00760	.380	1.3×10^{-8}
448.6	.00775	.388	7.8×10^{-9}
472.8	.00795	.398	6.3×10^{-9}
496.8	.00830	.415	5.6×10^{-9}
568.7	.00930	.465	5.0×10^{-9}
600.1	.00990	.495	1.1×10^{-9}
616.7	.01040	.520	1.2×10^{-8}
641.1	.01015	.508	1.1×10^{-8}
664.7	.00980	.490	1.0×10^{-8}
736.8	.01150	.575	9.9×10^{-9}
760.7	.01190	.595	8.6×10^{-9}
784.7	.01310	.655	9.7×10^{-9}

TABLE XIX (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
808.5 Hours	.01235	.618	9.4×10^{-9}
832.5	.01270	.635	9.4×10^{-9}
904.5	.01350	.675	9.2×10^{-9}
929.4	.01370	.685	8.6×10^{-9}
952.6	.01410	.705	8.5×10^{-9}
976.8	.01445	.722	7.0×10^{-9}
1001.8	.01460	.730	8.2×10^{-9}
1072.5	.01540	.770	8.0×10^{-9}
1144.8	.01660	.830	7.8×10^{-9}
1240.7	.01775	.888	7.8×10^{-9}
1312.7	.01830	.915	5.6×10^{-9}
1408.5	.01925	.962	5.0×10^{-9}
1480.7	.01960	.980	4.0×10^{-9}
1577.3	.02150	1.075	4.0×10^{-9}
1652.0	.02190	1.095	4.2×10^{-9}
1744.9	.02265	1.132	2.7×10^{-9}
1817.7	.02295	1.148	3.6×10^{-9}
1912.9	.02475	1.238	3.8×10^{-9}
1989.8	.02630	1.315	3.1×10^{-9}
2079.7	.02660	1.330	2.3×10^{-9}
2151.8	.02835	1.418	3.8×10^{-9}
2247.6	.02825	1.412	3.4×10^{-9}
2319.8	.02925	1.462	2.8×10^{-9}
2415.7	.03100	1.550	2.6×10^{-9}
2487.6	.03110	1.555	3.5×10^{-9}
2584.0	.03135	1.568	3.0×10^{-9}
2655.7	.03265	1.632	2.6×10^{-9}
2752.0	.03315	1.658	2.6×10^{-9}
2823.7	.03380	1.690	2.3×10^{-9}
2944.2	.03465	1.732	2.2×10^{-9}
2991.7	.03580	1.790	2.0×10^{-9}
3099.2	.03665	1.832	2.1×10^{-9}
3159.4	.03785	1.892	1.8×10^{-9}
3183.4	.03815	1.908	1.6×10^{-9}
3255.5	.03785	1.892	2.0×10^{-9}
3327.9	.03905	1.952	2.1×10^{-9}
3423.6	. 3975	1.988	1.8×10^{-9}
3495.7	.04005	2.002	1.8×10^{-9}

TABLE X1X (Continued)

Time	Length Change L (inch) (2" G.L.	Creep (%)	Pressure (Torr)
3591.9 Hours	.04145	2.072	1.9×10^{-9}
3663.6	.04180	2.090	1.9×10^{-9}
3783.6	.04345	2.172	1.7×10^{-9}
3832.2	.04445	2.222	1.8×10^{-9}
3927.7	.04495	2.248	1.5×10^{-9}
4008.7	.04615	2.308	1.6×10^{-9}
4095.4	.04690	2.345	1.8×10^{-9}
4171.2	.04735	2.368	1.6×10^{-9}
4263.9	.04860	2.430	1.4×10^{-9}
4335.4	.04895	2.448	1.4×10^{-9}
4431.8	.04930	2.465	1.7×10^{-9}
4504.0	.05095	2.548	1.6×10^{-9}
4599.6	.05065	2.532	1.6×10^{-9}
4671.2	.05230	2.615	1.6×10^{-9}
4767.5	.05400	2.700	1.6×10^{-9}
4839.3	.05415	2.706	1.4×10^{-9}
4936.2	.05525	2.762	1.3×10^{-9}
5007.5	.05600	2.800	1.5×10^{-9}
5103.3	.05740	2.870	1.5×10^{-9}
5296.0	.05865	2.932	1.4×10^{-9}
5343.1	.05915	2.958	1.3×10^{-9}
5439.6	.06010	3.005	1.4×10^{-9}
5511.2	.06125	3.062	2.0×10^{-9}
5679.6	.06255	3.128	1.3×10^{-9}
5775.4	.06425	3.212	1.3×10^{-9}

Test in Progress
Specimen B-24

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